FINAL REPORT

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DEVELOPMENT AND QUALITY OF GLABROUS CANARYSEED

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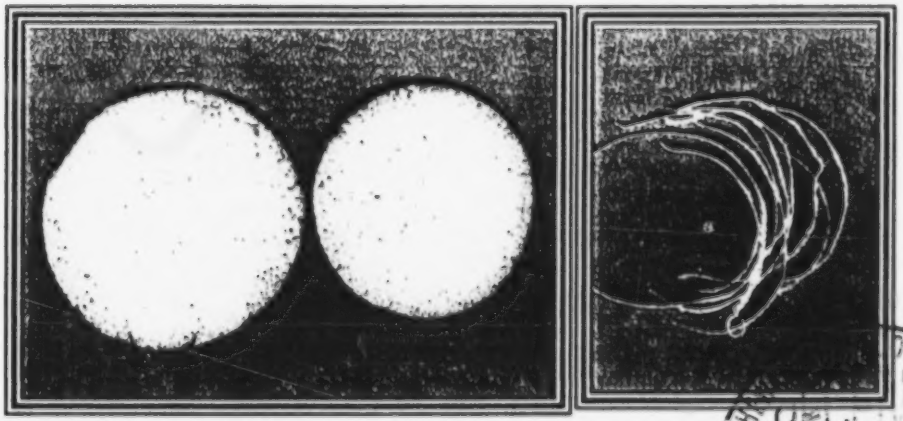
"DEVELOPMENT AND QUALITY OF GLABROUS CANARYSEED"

FINAL REPORT
(April 1, 1997 - March 31, 2001)

Principal Investigator:
P. Hucl

Co-investigators:
H. L. Han
E. M. Abdelaal
G. R. Hughes

Crop Development Centre,
Department of Plant Sciences,
University of Saskatchewan, Saskatoon, SK.



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(a) SUMMARY

During the course of this project a complete quality evaluation was conducted on the cultivar, CDC Maria. Phytochemical analysis of canaryseed demonstrated similarity with wheat in most cases. Alkaloids and other antinutritional factors did not appear to be present in significant amounts. CDC Maria canaryseed flour exhibited dough-forming characteristics, allowing for blending with wheat. Canaryseed products such as flour, starch, protein, oil and fiber showed potential for utilization in food and non-food products. Processing methods for canaryseed, including dehulling, milling, bleaching, roasting and component-separation were evaluated and optimized. Poultry feeding trials indicate that glabrous canaryseed can replace wheat in feed rations. Toxicology experiments suggest that dehulled glabrous canaryseed behaves in much the same manner as common wheat.

The first experimental glabrous canaryseed lines from planned crosses were yield-tested at multiple sites in 1999. A number of elite lines were re-tested in 2000.The most promising lines were 9-14% higher yields than CDC Maria with improvements in leaf mottle reaction.

(b) TECHNICAL REPORT

1. Background and Objectives

Canary seed (Phalaris canariensis) or annual canary grass has become a major alternate crop in Western Canada particularly in Saskatchewan which accounts for over 90% of Canadian canary seed production. It is a cereal crop which has only one use; bird food mixtures. The value of annual Canadian exports has averaged $48 million (Sask. Agric. And Food, 1999). Dehulled

canary seed or canary seed groat was found to contain acceptable levels of starch, protein and oil with unique properties for each component (Abdel-Aal et al 1997), having potential for use in the food and non-food industries. There are no available quality standards for canary seed as a human food due to its limited use. The current bird-feed market for canary seed requires hulled grains with less than 2% dehulled and/or foreign seeds. In addition, The current commercial cultivars are not well suited for developing canary seed for human consumption and processing because the hulls of these cultivars are covered with small silicified hairs or spicules that can contaminate the groat during dehulling. These hairs are a problem in canary seed production as they cause irritation to combine operator and grain handlers. Also, these hairs may be carcinogenic (Newman and Mackay, 1983) when present as a contaminant in wheat flour used in baking bread. The availability of hairless glabrous yellow-seeded canary seed cultivar will pave the way for developing canary seed as a food crop.

The objectives of this project were to develop cultivars of canary seed suitable for human consumption and adapted to Saskatchewan growing conditions. Glabrous cultivars with improved resistance to Septoria leaf mottle were a major breeding objective. Alternate uses for canary seed were investigated through detailed quality testing and the determination of nutritional components.

2. Project activities

2.a. Achievements

CDC Maria, the first hairless ("itchless") cultivar was Registered in 1997. CDC Maria is

currently the sole cultivar eligible for the " trademark being implemented by the Canadian Special Crops Association.

In June 1999 we submitted a full proposal to Health Canada in order to have glabrous canaryseed considered for human consumption. At this time we are awaiting a response from Health Canada.

In 1999 we conducted a number of poultry feeding trials (J. Ram and H. Classen). The results of that research are promising. After consulting with Health Canada we initiated (February 2000) a toxicological study using rats. The results of that research are summarized later in this report.

Our first replicated field trials of glabrous canaryseed from controlled crossing were conducted in 1999. A number of experimental lines looked quite promising, yielding 6-12% higher than CDC Maria. These lines and others, were re-tested in 2000, maintaining their yield advantage over CDC Maria. The first glabrous, yellow-seeded experimental line was yield-tested in 1999. The line in question yielded the same as CDC Maria.

Canaryseed products such as canaryseed flour, starch, protein, oil and fiber were successfully separated and each component held promise for utilization in the food industry. Canaryseed flour for producing cookies, protein isolate as a nutritional supplement and oil as a source of highly unsaturated fatty acids can be utilized. Canaryseed starch, with some degree of

modification, exhibited excellent functional properties which could be used in a wide range of food applications.

A continuous dehulling process using cone-type dehuller was developed.

2.b. Papers written

Abdel-Aal, E-S.M., Hucl, P., Sosulski, F.W. 1997 Characteristics of canaryseed (*Phalaris canariensis* L.) starch. Starch/Staerke 49:475-480.

Abdel-Aal, E-S.M., Hucl, P., Sosulski, F.W. 1997 Structural and compositional characteristics of canaryseed (*Phalaris canariensis* L.). J. Agric. Food Chem. 45:3049-3055.

Pierre Hucl, E-S.M. Abdel-Aal, G.R. Hughes A., F.W. Sosulski and A. Vandenberg. 1998. Recent developments in canaryseed research. 1998 Soils and Crops Update, February19-20, 1998.

Cultivar description of CDC Maria (Pierre Hucl et al. 2001. CDC Maria annual canary grass. Can. J. Plant Sci. 81:115-116).

3. Results and conclusions

3.1. Breeding of improved glabrous canaryseed

CANGLB2 glabrous canaryseed line was registered as CDC Maria in June 1997. CDC

Maria entered commercial production in 1999.

Fifteen yellow- seeded and three light brown (hairy) canaryseed lines were evaluated at two sites in 1997 using a 3-rep RCBD. The results of that trial are presented in Table 1.

The yellow-seeded lines (CY179 to CY193) under evaluation were equal or superior to the conventional checks in yield with a slight tendency to later maturity. Thus, yellow seed does not appear to confer a yield penalty.

Three reselected glabrous lines (Trts. 4-6) were evaluated in the trial along with the yellow seeded material. These lines yielded 4-6% higher than CDC Maria. The three lines represented the highest yielding material obtained from the reselection of four glabrous sister lines (one of which was Canglb2) in 1994.

One of the reselected glabrous canaryseed lines (C96020) was evaluated in replicated (2 reps/site at 5 sites, 3 reps at 2 sites). When averaged with the data from three trials in 1996 (Table 2) the new glabrous line showed only a slight (2%) yield improvement over CDC Maria. Thus, this reselected material was not advanced any further. Our efforts were concentrated on accelerating the development of breeding material from controlled crosses. This material constituted the first attempt at breeding canaryseed through controlled crossing. To date there had been no such efforts reported in the literature globally. In 1997, 950 glabrous F5 hills from the cross Cantate/CDC Maria were grown at Saskatoon in a disease nursery. Spreader rows of

Keet were planted two weeks ahead of the breeding material. The hills were planted by hand. When the hills reached the four leaf stage, septoria-infested straw was spread throughout the nursery. Due to the very dry conditions in July of 1997, the nursery was emergency-irrigated via water-tanker. No disease development occurred. Thus, selection was carried out on the basis of plant height and panicle size. Of the 955 hills, 307 were harvested and threshed. A further 1813 hills of the same cross were grown as F4 hills in the same nursery, with equal selection pressure.

The first glabrous/yellow seed F4's (n=8) were grown in hills in 1997. A further 500 F4 and 338 F3 hills from five CDC Maria/SR crosses were grown in 1997.

In addition, 44 F2 bulk plots of the cross CDC Maria/Cantate were grown and single plants selected. A further 10 random-pollinated populations were grown for single plant selection purposes.

In order to determine the inheritance of the glabrous trait, F2 populations of 6 crosses were hand space-planted. A single panicle was harvested from each plant (n=6,000) and examined for pubescence. The same F2 populations were also grown in bulk plots at half the normal seeding rate and 2,750 plants sampled. In addition, 3,400 F2 plants from random crosses in which CDC Maria was the female parent were assayed. The results of the space seeded material are presented in Table 3.

The glabrous trait is simply inherited based on field and greenhouse results.

We obtained a 3:1 ratio of pubescent:glabrous plants.

Two F2 populations segregating for seed colour were examined.

The light-yellow seed coat colour is controlled by a single gene and is recessive to brown seed coat colour (Table 4).

A gametocide-facilitated crossing program was conducted during the summers of 1997 to 2000. Two seeding dates were used. The following populations were initiated:

CX97.1 = Cantate/CDC Maria//Cantate

CX97.2 = Cantate/CDC Maria//CDC47

CX97.3 = Cantate/CDC Maria//CDC50

CX97.4 = CDC Maria/CY184//CDC47

CX97.5 = CDC Maria/CY184//CY15

CX97.6 = CDC Maria/CY184//Cantate/CDC Maria

CX97.7 = CDC Maria/CY15

CX98.1 = Cantate*3/CDC Maria

CX98.2 = Cantate*2/CDC Maria//CY186

CX98.4 = CDC Maria/CY184(GYF5)//CY186

CX98.5 = CDC Maria/CY184(GYF5)//PI170167

CX98.6 = CDC Maria/CY184(GYF5)//PI284184

CX98.8 = CDC Maria/CY184(GYF5)//PI189547

CX99.1 = CX98.1/Cantate

CX99.3 = C99005/CX98.1

CX99.4 = CX98.1/C99019

We conducted a replicated experiment to verify the leaf mottle resistance of five canaryseed accessions in 1997. Two sites were lost, one to rabbits the other to herbicide damage. The remaining three experiments consisted of a split plot design in which half of each plot was to be protected with a fungicide. One trial (North Seed Farm - mist irrigated) was sprayed. Disease development was insignificant in all three trials. However, the effort was not wasted as one accession yielded 14% better than the checks and was used as a parent in 1998.

In addition, we grew out and screened the USDA canaryseed collection for seed size and found one accession with kernel weight 25% heavier than that of the checks. This line was used to introduce more genetic variability into the breeding program.

The 1998 growing season at Saskatoon was characterized by a very dry spring with no significant rainfall until the last weeks of June. The canaryseed nursery was nearly lost due to herbicide injury due to the crop being under stress at the time of chemical application. The nursery eventually re-grew and was set back three weeks in its development. In order to avoid losing a

year of yield-testing in 1999, a larger-than budgeted for winter nursery was grown in New Zealand.

In excess of 500 glabrous breeding lines were evaluated in unreplicated micro-plots (1.3 x 1.3 m) with repeated check plots at Kernen in 1998. The majority of these lines resulted from crosses between CDC Maria and leaf spot resistant accessions and constituted the first attempt at breeding canaryseed through controlled crossing. The lines originated from hill plots harvested in 1997. These lines were evaluated for grain yield, maturity, plant height, test weight and kernel weight. Of the 527 lines, 35 were advanced to a multi-site trial in 1999. One glabrous yellow-seeded line was included in this advanced trial. A second group of lines was grown at two sites in 1999. Lines (n=430) which had insufficient seed for micro-plots in 1998 were grown in rows instead. Those lines were grown in unreplicated trials in 1999.

Two replicated, multi-location yield trials were conducted in 1999. One trial provided usable data from 4 sites, the other from 3 sites. A total of 68 lines were tested. Of those lines, a dozen were retained for re-evaluation in 2000. The best of the glabrous experimental lines yield 12% than CDC Maria. One of the lines was yellow-seeded. This line represents our first prototype for human consumption and resulted from a planned cross.

The 1999 growing season at Saskatoon was cool and wet – the opposite of 1998. No herbicide injury was encountered and all plots grew well. Some lodging was observed in the later-seeded plots. Leaf mottle appeared in early August as did aphids. Yield levels were in the 1,800 to

2,000 kg/ha range. 1999 represented our first replicated, multi-location field testing season for experimental lines we started developing in 1995-1996.

Leaf mottle development was pronounced at one of our sites. Infested straw was spread throughout our nurseries. The disease was evident on the crop stubble. No genotypic differences in stubble coloration were observed in 1999.

In excess of 1,300 new glabrous breeding lines were evaluated in unreplicated plots (1.2 x 3.6 m) with repeated check plots at Kernen in 1999. In addition, 600 lines were grown in single-row plots (3.6 m long). Approximately half of the lines were culled on the basis of height and maturity and were not harvested.

In excess of 2,000 lines were grown in hills in our main nursery at the Kernen Research Farm in 1998 and 1999. The populations traced back to crosses made in 1996 and 1997. Approximately 15% and 20% of the hills were harvested and tested either in rows or micro-plots in 1999 and 2000.

The highest yielding lines from the 1999 trials were grown at 5 sites in 2000. The data averaged over years is presented in Table 5. Based on eight site-years of data we have been able to obtain lines that are 9-14% higher yielding than CDC Maria with similar maturity and height. Of interest is the leaf mottle data collected in 2000. Disease severities in 2000 were higher than in the previous three years. As a reference point, the best accessions we have screened from the

world collection would have had a score of -2.0 (ie 2 units less disease than the check). In this case the check had a score of 3.0. A slow-mottling line would have had a score of 1.0. The line C99050 is midway between CDC Maria and the target level of resistance. Thus we have accomplished our objective of selecting glabrous lines with improved yield and a higher leaf mottle resistance than CDC Maria. The test weights and kernel weights of the lines in this test were equal to or higher than those of CDC Maria.

Two lines, C99005 and C99048, were also tested in regional trials in 2000. Five sites produced usable data. Averaged over the five trials C99005 and C99048 yielded 4.4 and 13.7% higher, respectively, than CDC Maria. C99005 is our first glabrous yellow-seeded line while C99048 is a brown-seeded glabrous line. C99005 is our prototype for a food-grade canaryseed.

Breeding lines obtained from the second cycle of crosses were evaluated in three replicated trials in 2000. The data for these lines is presented in Table 6. The best line yielded 34% higher than CDC Maria and had the best disease score in the test. Thus, if this field trial is any indication, we should be able to increase the yield level by 20% relative to CDC Maria. As was the case for the lines presented in the previous table, test weights and kernel weights were similar to or higher than those of CDC Maria.

In addition to the above two trials, another two trials containing a total of 68 experimental lines were grown in the Saskatoon region in 2000. Approximately 20 lines warrant re-testing. A series of unreplicated yield trials were grown in 2000. A total of 550 new experimental lines were evaluated. After culling for yield, maturity, disease reaction and test weight, about 10% of the

lines were retained. Earlier generation material was grown in hills and bulks and selections were made from the nurseries in question. Four new crosses were made during the summer of 2000 and the putative F1's were grown in a greenhouse during the winter of 2000/2001.

3.2 Novel Food Status

An official data package in support of using canaryseed for human consumption was submitted to Health Canada in June 1999. This was the third document submitted. Since canaryseed has no history of human consumption in Canada it is considered a Novel Food and as such has to be scrutinized by Health Canada.

Two data requirements added in early 1999 were completed (heavy metal content of the grain and mycotoxin levels). As indicated in our previous report we were not able to complete the data collection for Novel Food requirements in 1998. Due to the stepwise and feed-back nature of the process we are not certain as to when we will complete this milestone as it is somewhat out of our control. However, we have submitted an official "Notification" to Health Canada using data collected up to mid-1999. This was done in June of 1999. We have received no response from Health Canada to date.

3.2.1 Feeding and toxicology trials

These experiments were conducted by Mr. Jason Ram in Dr. Hank Classen's laboratory (Dept. of Poultry Science, University of Saskatchewan).

AFIF Summary Report: Canaryseed Feeding Studies in Broiler Chickens

Two preliminary broiler chicken studies were conducted to determine the nutritional value and potential toxicity of two canaryseed cultivars (CDC Maria and Keet) vs. a hard red spring wheat (CDC Teal). A nutrient retention trial determined the apparent metabolizable energy (AME_n) as well as the protein, starch and fat digestibility of the various seed types. The nutritional information gathered was used to formulate balanced diets for the subsequent broiler chicken performance trial to evaluate the growth and toxic potential of the canaryseed.

On a dry matter basis, the AME_n of CDC Teal wheat, dehulled and hulled (hulls included) CDC Maria, and hulled Keet was determined to be 2303, 3867, 3205, and 3292 kcal/kg, respectively (Figure 1). The dehulled CDC Maria has a significantly higher AME_n compared to the hulled canaryseeds which, in turn, have significantly higher AME_n than CDC Teal wheat. CDC Teal wheat, dehulled and hulled CDC Maria, and hulled Keet had similar protein digestibilities of 86.1, 86.4, 88.3, and 86.2%, respectively. The dehulled CDC Maria was significantly ($P<0.05$) more digestible than CDC Teal wheat in terms of starch (97.9 vs. 86.0%) and fat (77.4 vs. 44.5%). The hulled CDC Maria and hulled Keet have similar starch but significantly ($P<0.05$) higher fat (87.7 and 90.8%, respectively) digestibilities compared to the dehulled CDC Maria. Thus, data from the nutrient retention trial suggests that the nutritive value of canaryseed is at least similar or superior to that of wheat.

In the 5-week performance trial, broiler chickens were fed the three canaryseed diets and the

control Teal wheat diet at a 50% concentration (mixed with corn and soybean meal). In Figure 2, total weight gain was similar between the hulled canaryseed diets and CDC Teal wheat; weight gain for birds on dehulled CDC Maria was similar to those on wheat, but was slightly lower than those on the hulled canaryseed diets ($P<0.05$). The average consumption of feed by the birds on the dehulled Maria canaryseed diet was significantly lower than birds on the hulled Keet diet, but was similar to both the Teal wheat and hulled Maria canaryseed diet. Overall results indicate that birds on the canaryseed diets fared just as well as birds on the CDC Teal wheat diet in terms of similar gain to feed ratios ranging from 0.609 to 0.635.

In the performance trial, no significant differences between diets were detected in broiler serum lactate dehydrogenase and creatine kinase levels which were measured to determine if possible toxic constituents from the canaryseeds were producing generalized cellular injury. There were also no significant differences in potential target organ weights (e.g., bursa, heart, kidney, liver, pancreas, spleen) when expressed as a percentage of body weight. The incidence of gizzard ulcers was similar for the CDC Teal wheat, dehulled and hulled CDC Maria diets. Hydropericardium severity in the hulled canaryseed diets was significantly higher vs. dehulled CDC Maria ($P<0.05$), but was similar to the wheat diet; there was also no difference between the wheat and dehulled CDC Maria diets.

In summary, the nutritional value of canaryseed in broiler chickens appears to be equal or better than that of wheat and the apparent absence of any obvious additional toxic effects compared to wheat make canaryseed a good candidate as a potential food supplement for human consumption.

Summary of Repeated Dose 91-day (13-week) Oral Toxicity Study of Canaryseed in Rats

Background:

In accordance to regulatory recommendations made by Health Canada for licensing novel foods, this study was conducted to determine the toxic effects, if any, of canaryseed in a longer term rodent study as part of the general safety assessment of canaryseed for human consumption.

The study compared the toxicological and growth effects of both canaryseed CDC Maria and Keet varieties with that of CDC Teal wheat (the control diet) in Sprague-Dawley rats using the protocol outlined in the OECD Test Guideline No. 408: Repeated Dose 90-day Oral Toxicity Study in Rodents.

Each of the four diet treatments studied consisted of a 50% concentration of either:

1. Dehulled "hairless" CDC Maria canaryseed (hulls removed);
2. Hulled "hairless" CDC Maria canaryseed (hulls intact);
3. Hulled "hairy" Keet canaryseed (hulls intact); or
4. CDC Teal wheat (Control diet)

The 50% test ingredient concentration was chosen to allow for the formulation of nutritionally equivalent diets (based on NRC specifications) with the use of relatively balanced amounts of other natural ingredients (e.g., corn, soybean, canola oil) and supplements (e.g., amino acids). Although the 50% concentration represents a dose level that is unlikely to be encountered in the normal human diet, this amount was chosen as it is representative of an extremely high dose exposure in the real

world. Since previous *in vitro* and broiler chicken subchronic performance/toxicity studies did not indicate the potential for major significant adverse effects, this artificially high level of the test ingredients in the rat diet is required to determine if there are toxicants contained in the canaryseeds that have the ability to induce detrimental health effects.

Protocol Summary:

Adult Sprague-Dawley rats just over 4-weeks old were fed the various diet treatments for a 91-day (13-week) period. Rats were acclimatized to laboratory conditions and to eating ground feed (commercial Prolab rodent diet) for 8-9 days prior to the start of feeding trials. Four test ingredients (including one control) at a 50% concentration were ground into a mash and nutritionally balanced to make up the four diet treatments. Following the OECD Test Guideline No. 408, there were 10 rats per sex per diet treatment giving a total of 80 rats. Therefore, this study consisted of two identical trials staggered 8 days apart to make sample collection within a one-day period more manageable. Each trial had 10 rats per diet treatment (5 male and 5 female) giving a total of 40 animals. Each rat was housed individually into randomly assigned shoebox cages. The diets were placed in special feed jars to allow for feed weigh backs. Daily clinical observations of the animals and weekly body weight and feed consumption measurements were conducted. Weekly detailed clinical observations were made on each rat noting any physical, physiological or behavioural changes. Monthly functional observational batteries (at 0, 1, 2 & 3 months) were performed on each rat to evaluate sensory reactivity to stimuli, grip strength (qualitative), and motor activity. Ophthalmological examinations were performed on each rat 2 days prior to the administration of the diet treatments and 1 day prior to the termination of each trial. Just prior to the end of each trial

(around week 12), the rats were individually transferred into metabolic cages for a 16 h period for urine collection (for urinalysis). At the termination of each trial, the rats were anesthetized with isoflurane and weighed before collecting blood samples via cardiac puncture. Rats were then euthanized with halothane before being dissected. Gross necropsies of the animals were conducted before the major internal organs (e.g., brain, heart, lungs, kidneys, liver, spleen, adrenals, testes, epididymides, uterus, ovaries, thymus, pancreas, esophagus, stomach, intestines, etc.) were removed and weighed. Bone marrow from the femur of each rat was smeared on glass slides (done within 20 minutes of euthanasia) for cytological examination. The organs, in addition to any other tissues that exhibited gross lesions, were preserved for future histopathological examination. A complete blood cell count and coagulation tests were performed on each rat to evaluate the blood system. Small animal panels were also performed on plasma derived from individual blood samples to evaluate some of the blood biochemistry parameters.

Daily Clinical Observations:

Daily observations were made to determine the clinical condition of the animals. These observations included any changes in the skin, fur, eyes, mucous membranes, secretions, respiration, posture, response to handling, or the presence of abnormal behaviour. In general, the health and behaviour of all the rats appeared to be normal.

Only the following clinical notations were made in few of the rats in the study: minor skin lesions (around the shoulder blades and nose region) which were likely caused by scraping or rubbing against the metal lids of the feeder jars containing the mash diets; the presence of minor ocular discharge stained with hematoporphryin exudate around the eye (observed as 'spectacle' eye) which

were likely caused an irritant in the eye region (e.g., shards of grounded hulls) causing excessive lacrimation; and minor hair loss in the forearms of two of the rats.

No presence of diarrhea was noted in any of the rats. Excessive water intake and urine production was noted in one rat on the dehulled CDC Maria diet (in month 2 and 3 of the trial) indicating urinary infection (urinalysis of this rat showed the presence of nitrate in the urine suggesting the possibility of infection) or hormonal disturbance. All other physiological functions and measured parameters in this rat, however, appeared normal.

Functional Observational Batteries:

Weekly and monthly functional observational batteries were conducted in each rat to assess sensory reactivity to different types of stimuli, as well as to assess grip strength (qualitatively) and motor activity.

Weekly individual rat observations included noting body posture on approaching the cage, presence of abnormal behaviour, level of palpebral (eyelid) closure, piloerection, biting, spontaneous vocalizations, ease of removing and handling the rat, fur and skin appearance, lacrimation or crustiness around the eyes, pupil size and response, and degree of salivation and respiration. The weekly functional observational battery also included a 1.5 min field test (on a cart) to observe individual rat behaviour (rearing, grooming, defecation, urination, and level of arousal) and motor function (locomotion activity and gait).

The monthly functional observational battery included the following additional assessments: approach, touch and startle response, tail pinch response, righting reflex, head shaking and toe pinch response, extensor thrust of rear feet, hind limb rotation, positive geotropism response, positional

passivity, a qualitative assessment of grip strength, ability to stay on a stationary and rotated bar, and hind leg splay measurements (done once only on week 12 of both trials).

In general, there did not appear to be any major 'abnormal' differences among the rats on the various diet treatments in terms of the parameters that were assessed. The few significant differences that were noted in the study were likely attributable to normal rat behaviour, intraspecies population variation, or incidental observations.

Organ Weights and Growth Data:

A comparison of rat organ weights among the test diets and a control diet provides information on whether the test substance (i.e., feed) is producing a gross toxic change in a particular organ or organs. The following organs were weighed in each rat: thymus, heart, spleen, liver, adrenal glands, kidneys, epididymides, testes, ovaries, uterus and brain. No significant differences in organ weights among diet treatments were observed, except for the liver. The rats on the dehulled CDC Maria canaryseed diet had significantly higher liver weights than rats on the hulled canaryseed diets, but were similar to those on the control CDC Teal wheat diet. When the organ weights were expressed as a percentage of body weight, there were no significant differences between diet treatments, except for the testes and brain weights. In both cases, rats on the dehulled CDC Maria canaryseed diet had significantly lower relative weights of the testes and brain compared to the rest of the other diets. However, rats on the dehulled CDC Maria canaryseed diet also had a significantly higher final body weight and weight gain than rats on the rest of the other diet treatments. This may have contributed to the comparatively lower relative organ weights, as it is unlikely that the testes and brain grow in a linear proportion to increasing body weight. Furthermore, histopathological

examination of the testes and brain tissues from rats on the dehulled CDC Maria canaryseed diet did not reveal any abnormalities (e.g. atrophy).

Feed consumption data shows no difference in between the various diet treatments. However, the gain to feed ratio was significantly higher with the dehulled CDC Maria canaryseed diet compared to the rest of the diets. This suggests that either the feed conversion efficiency of the dehulled CDC Maria canaryseed diet was superior to that of the other diets, or that its nutritional value in general was underestimated.

Plasma Biochemistry Analyses:

The clinical chemistry screen measures the various chemicals in the blood and provides an indication of functional changes at the organ and tissue level. There were no significant differences between rats on the dehulled CDC Maria canaryseed diet and rats on the CDC Teal wheat (control) diet in terms of the blood sodium, potassium, chloride, bicarbonate, calcium, phosphorus, urea nitrogen, creatinine, glucose, cholesterol, bilirubin, albumin, globulin, alkaline phosphatase, sorbitol dehydrogenase, gamma glutamyltransferase, and creatine kinase levels.

The blood alanine aminotransferase activity in rats on the dehulled CDC Maria canaryseed diet was significantly lower (suggesting "less liver damage") than that of the rats on the control CDC Teal wheat diet.

Urinalysis Analyses:

Urinalysis was done to look for certain substances that are not normally present in the urine. The leukocyte, nitrite, pH, protein, glucose, ketone, urobilinogen, bilirubin, and blood content were

determined in the urine. The urine collection had to be staggered over a period of 4 days for each rat trial, as there were only 12 metabolic cages available at a time. Urine collection was done around week 12 of the 13-week study. Despite efforts to minimize feed contamination of the urine, this was an unavoidable artifact found in almost all samples at varying degrees.

The overall results from the urinalysis indicates that there may be a difference in the pH and glucose levels in rats on the dehulled CDC Maria canaryseed (lower pH and higher glucose levels) compared to the CDC Teal wheat diet. A corresponding elevated glucose level in the rats on the dehulled CDC Maria canaryseed diet was not observed in the plasma chemistry analyses. However, due to limitations of available equipment and potential feed contamination problems, this assay may not be as reliable as the other physiological chemistry analyses in terms of its diagnostic value.

Complete Cell Blood Count (CBC) Analyses:

A complete cell blood count was performed on each rat blood sample to measure the hematologic parameters of the blood. Included in the CBC analysis was a white blood cell (WBC) or leukocyte count, red blood corpuscle (RBC) or erythrocyte count, a hemoglobin assay, a hematocrit, a calculation of mean RBC volume and distribution width, a reticulocyte count, a WBC differential, and plasma total solids. There were no significant differences among the rats on the various diet treatments in any of the CBC parameters.

Discussion of Bone Marrow Smears:

Histological examination of the marrow smears was conducted on 2 out of 5 rats/diet treatment/sex/trial. A change in marrow cellularity (the number of cells of the various nucleated cells

found in the marrow) may indicate that a toxic agent(s) could be affecting the marrow precursor cells. Although microscopic cell counts on marrow cells are subject to questions of accuracy, it does give a general account on the overall state of marrow function of the rat.

No significant differences were observed between diet treatments in the following parameters: the erythrocytic proliferating pool ($E_{(p)}$); erythrocytic maturation pool ($E_{(m)}$); granulocytic proliferating pool ($G_{(p)}$); granulocytic maturation pool ($G_{(m)}$); maturation index erythrocytic series ($MI_{(E)}$); maturation index granulocytic series ($MI_{(G)}$); and the granulocytic to erythrocytic ratio (G:E).

Although there was a significant difference in the mast cell number between rats on the hulled CDC Maria diet and rats on the CDC Teal wheat diet, mast cell numbers in rats on the dehulled CDC Maria and the hulled Keet diets were statistically similar to that of rats on the CDC Teal wheat diet. Compared to the mast cells of tissue origin (e.g., blood vessels), the relative number of mast cells originating from the marrow is likely too few to be of significant consequence physiologically.

Coagulation Test Analyses:

A shortened or prolonged Prothrombin Time (PT)/activated partial thromboplastin time (APTT) test when compared to the control would suggest a deficiency in the activity of one or more of the factors involved in blood-clotting process, or the presence of a chemical inhibitor of blood coagulation in the diet. There were no significant differences among the rats on the various diet treatments in terms of PT and APTT.

Ophthalmological Examinations:

Ophthalmological examinations were performed on each rat 2 days prior to the administration

of the test diets and 1 day prior to the termination of each trial. Some transient congenital findings (e.g., tunica vasculosa lentis, pupillary membrane and hyaloid artery remnants) were noted in the pre-trial examinations. Most of these transient congenital ocular findings were not detected upon the subsequent ophthalmological examination. No abnormalities were detected in the eyes of most rats following complete ophthalmological examinations. A few lesions were noted in a few of the rats; however, the majority of lesions found were from rats on the CDC Teal wheat diet. These lesions were likely incidental and not associated with any particular diet treatment.

Gross Necropsy and Histopathology Results:

All rats underwent gross examination after being euthanized. Minor lesions were noted in some of the rats. Pathologic evaluation was performed to identify morphological changes at the organ and tissue levels. For this study, 32 out of a total of 80 rats were randomly chosen for full histopathological investigation (i.e., 2 out of 5 rats per treatment/sex/trial). The noted lesions included: chronic (renal) pyelitis; mild renal tubular necrosis; focal renal scar; cystitis – mild, chronic; tracheitis - mild, chronic; lung - focal alveolitis; lung - histiocytosis – mild; lung - focal osseous metaplasia; myocarditis - multifocal, subacute; endometritis - mild, subacute; cataract – mild; intestine - focal fibrosis; solitary omental/peritoneal nodules; and ovarian cyst. The lesions listed above are not associated consistently with any one particular diet treatment and appear to be miscellaneous, mostly very mild changes, including mild inflammatory lesions in various tissues.

Conclusions:

The overall findings of this study do not show any major adverse toxic effects in rats fed the

dehulled CDC Maria canaryseed diet as compared to the control CDC Teal wheat diet. The miscellaneous differences observed by the various analyses, assessments, and evaluations conducted in this study appear to be minor and sporadic. These findings tend to suggest that there is does not appear to be a toxic effect to any specific target organ when rats were fed the dehulled CDC Maria canaryseed. Furthermore, the inclusion level of canaryseed in the test diets (i.e., 50%) is far beyond what would be expected in a normal human diet. Given the relative lack to overt toxicity shown in this study, it is very unlikely that the much smaller inclusion level of dehulled CDC Maria canaryseed in the human diet would produce any significant toxic effects in general.

3.3. Canaryseed Processing

3.3.1. Dehulling Process

The dehulling process study was conducted in collaboration with Drs. Sokhansanj and Crerar in the Department of Agricultural and Bioresource Engineering, University of Saskatchewan. The main goal was to develop a dehuller capable of removing canaryseed hulls in an efficient manner, i.e. maximize percent of dehulled seeds and minimize percent of broken seeds and seeds with hulls.

The size and shape of canaryseed were determined by measuring the major and minor axis using an image analysis system (Matrox Inspector, Matrox Electronics, Lavalle,QB). The system consisted of a video camera and PC computer. The analysis was carried out on over 200 of hulled seeds and 200 of dehulled seeds (groats). The hulls were removed manually.

The dehulling process was carried out with a cone-type dehuller, designed and constructed

in the Agricultural and Bioresource Engineering Laboratory, University of Saskatchewan. This device consisted of a hopper (1) a guillotine-type seed flow regulator, (2) a shroud section, (3) a rubber lined screen section, (4) a rubber-coated aluminum cone mounted on a splined shaft, (5) a height adjustment rod, (6) a bucket collection system, (7) a cyclone for dust collection, (8) a shaft receiver/bearing permitting vertical shaft movement, (9) a motor and pulley drive system and (10) an inverter speed control (Fig. 3).

The canaryseed was weighed into 500.0g sample lots using a Mettler PL1200 analytical balance (0.01g) (Mettler Instrumente AG, Zurich, Switzerland) and the masses recorded prior to dehulling. The fines, hulls, and intact seed were collected in separate pails.

The contents of the pails were then aspirated using a Superior Fractionating Aspirator (Carter-Day Co., Minneapolis, MN) to separate the hulls from the sample. The hulls and aspirated seed remaining were weighed and then the masses recorded. The success of dehulling was characterised by manual inspection of a 20g sub-sample from the aspirated seed. This representative sample was then separated manually into three categories, seed with hull, seed without hull, and broken or damaged seed. Each category of seed was then weighed using an Ohaus Galaxy 160D analytical balance (.0001 g) (Ohaus, Florida Park, NJ) and the mass recorded.

The following terms were defined to evaluate dehulling effectiveness:

% Broken = [mass of broken or damaged seeds/mass of aspirated subsample]

% With hulls = [mass of seeds retaining hulls/mass of aspirated subsample]

% Dehulled = [mass of seeds without hulls/mass of aspirated subsample]

$$D_{eff} = \frac{1}{m_s}\left[\left(m_c + m_{hr}\right) - \left(m_{ud} + m_{br}\right)\right]$$

where

D_{eff}- is the dehulling effectiveness index

m_s - is the mass of the original sample (approximately 500.0g)

m_c - is the mass of dehulled cotyledon (est. from sub-sample*)

m_{hr} - is the mass of hull recovered by aspiration, g

m_{ud} - is the mass of seed with hulls (est. from sub-sample*)

m_{br} - is the mass of broken seed (est. from sub-sample*)

Mass of each category in the original sample was estimated by multiplying the mass of that category found in the 20g sub-sample by the ratio of the aspirated sample mass to the sub-sample mass.

The presence of broken or damaged seed is undesirable and hence must be minimized. The percentage of successfully dehulled seed should be maximized. The dehulling effectiveness index is

a performance index which penalizes operations which result in excessive breakage or incomplete dehulling (Sokhansanj, 1997). The theoretical range of D_{eff} is from -1 (complete destruction of seed) to +1 (perfect dehulling without waste).

Preliminary experiments were conducted to determine the optimal speed and flow rate for further testing. Speed settings of 700, 900,1100, and 1300 rpm and flow rate settings of 0.95, 4.48, and 8.70 kg/min. Trial runs were performed as a four by three factorial with duplication. Sample sizes for this test were approximately 500.0g each.

Once optimal speed setting and feed rate were determined further experiments were conducted to test if seed treatment increased dehulling effectiveness. Both the type of treatment and number of passes through the machine were examined.

Two types of treatments were performed. Grain was conditioned either by moisturizing or heating prior to dehulling. Moisturizing of the grain was carried out by spraying distilled water on pre-weighed samples of canaryseed to a predetermined moisture level depending on the initial moisture content of the grain (12,14, and 16% w.b. final moisture content). The moisturized grain lots were allowed to temper for 18 hours prior to dehulling.

Heating was carried out in two ways, either using fluidized bed dryer (Lab-Line Instruments Inc., Melrose Park, IL) or a "reel" type oven (National MFG. Co., Lincoln , NB). Approximately 150g seed samples were placed into the fluidized bed dryer, which was operated at an inlet air

temperature of 90 °C and blower speed setting of 7, for 3 minutes. For the oven treatment approximately 70g seed samples were spread into 228.6mm (9inch), square cake pans and placed into the reel oven which was set at 250°C for 1 min. After heating, the grain was allowed to cool to ambient temperature prior to dehulling.

To determine if multiple passes improved dehulling effectiveness seeds were passed through the dehulling machine twice. After the first dehulling pass, seeds were aspirated, the hulls removed, and the sample run through for a second pass.

The rotational speed was set at 1100 rpm and the flow rate was set at 0.95 kg/min for testing. Original sample sizes of approximately 500.0g were used in all experiments.

Dehulling effectiveness results were statistically analyzed using the SAS software (SAS Version 6, 4th Ed., 1989, SAS Institute Inc., Cary, NC).

Data in Fig. 4 shows normal probability curves fitted for width and length, respectively. These curves were fitted from seed with and without hulls which were measured by machine vision. It is apparent that substantial overlap of the width curves indicates that separation by width, as by sieving, would not be a practical method of separating dehulled from non-dehulled kernels. The length curves lie more completely apart, so that separation by indent cylinder may be practical. It may also be possible to separate dehulled from non-dehulled seeds by mass and/or fluidization velocity (e.g. by gravity table). Nevertheless, it is highly desirable to dehull the seed as completely as possible while

minimizing losses from broken or damaged seed, without recourse to further processing.

The variation in dehulling effectiveness, a function of machine speed and seed flow rate, as determined in preliminary tests is reported in Table 7. Based on these results, a machine speed of 1100 rpm, and feed rate of 0.95 kg/min were used as the test operating conditions for subsequent runs. These conditions resulted in the highest dehulling effectiveness (0.85) of all the tests performed, with percent of aspirated seed sample dehulled (91.3%), and percent of aspirated seed sample retaining hulls (2.4%) statistically not different from the optimal numerical values achieved. The percentage of broken seed in the aspirated seed sample (6.1%) with a speed of 1100rpm was higher than that obtained for lower dehulling speeds. However, 6.1% percent broken seed was statistically the same or lower than values obtained at a dehulling speed of 1300 rpm. It was hoped that pre-treatment would result in increased dehulling effectiveness while lowering the amount of sample which was broken during testing.

The dehulling effectiveness obtained by pre-treatment of seeds prior to dehulling is shown in Table 8. The results obtained without pre-treatment are shown as "control". For all treatments the percentage of broken seed in aspirated seed sample was not improved when compared with the control. The percentage of seeds retaining hulls in the aspirated seed sample were reduced by passing samples through the dehuller twice. None of the treatments resulted in a significant improvement in percent of aspirated seed sample dehulled or dehulling effectiveness. It was concluded that the pre-treatments tested were ineffective in increasing dehulling effectiveness. The dehulling surface area should be increased to achieve similar effects to repeat passes.

Anecdotal evidence indicates that broken seeds can be removed from the dehulled sample by sieving with a number 16 Tyler sieve (1.19mm openings).

Based on the tests and resulting observations, the following conclusions and recommendations are made:

Based on image analysis seed measurement, it is impractical to separate dehulled from undehulled seed by width, but length separation of dehulled and undehulled seeds may be possible.

Based on preliminary trials a machine speed of 1100rpm and a flow rate of 0.95 kg/min were selected as operating conditions.

Pre-treatments, including moisture treatment conditioning to 12, 14, and 16% w.b., oven heating to 250°C for one minute (moisture content of 10% w.b.), and fluidized bed heating to 90°C for three minutes (moisture content of 10% w.b.) did not significantly increase dehulling effectiveness when compared with non-pretreated seed.

Passing the seed twice through the dehuller resulted in significant lowering of the percentage of seeds retaining hulls in the aspirated seed sample (0.29%) when compared with one pass (2.41%). The percentage of broken seed in the aspirated seed sample and the dehulling effectiveness were not changed.

The cone-type dehulling machine, equipped with rubber dehulling surfaces performed well at

one pass dehulling without pretreatment. After aspiration, less than 2.5% of seed had remaining hull.

The dehuller surface area should be increased to improve dehulling efficiency.

Broken or damaged seed should be removed from the sample by sieving, hulls should be removed from the sample through aspiration, and the undehulled seed could possibly be removed by indent cylinder, gravity table, or air screening to improve sample quality.

An abrasive surface to debran dehulled seed should be examined so that further processing can be accomplished with the same equipment.

Incorporating aspiration in the dehuller operation should be considered to reduce processing time.

3.3.2. Milling Process

A Brabender Quadrumat Jr. roller mill was evaluated in separation of the branny materials (seed coat and germ) from the starchy endosperm of CDC Maria into two milled products, bran and flour, respectively. The effects of tempering moisture level (10-16%) on flour yield, color and ash content were investigated. Soaking (overnight) and drying the seeds at different temperatures (at 50°C overnight, at 100°C for 5 hr and at 130°C for 1 hr) prior to milling were also investigated. The effect of roasting at three temperatures (250, 300 and 350 °C) on milling quality of canaryseed was also studied. The results of these experiments are presented in Figs. 5-10.

Flour yield of canaryseed was dramatically affected by tempering moisture level with or without additional sifting (Fig. 5). As the tempering moisture was increased, canaryseed flour yield decreased due to very soft endosperm which is broken down into small pieces attached to the seed coat. Soaking and drying at low temperature (50°C) to 14.0% moisture content prior to milling resulted in an increase in flour yield (Fig. 6). Drying at higher temperature, however, showed an adverse effect on canaryseed flour yield. The same finding was observed when canaryseed groats were roasted (Fig. 7). Despite the differences in flour yields resulting from using different tempering moisture levels, slight differences in Hunterlab color scores (L, a and b) were found among canaryseed flours (Fig. 8). Slight changes were also observed in color of the flours due to soaking and drying (Fig. 9) or roasting treatments (Fig.10). Ash content of canaryseed flours declined as tempering moisture level increased (Fig. 11), which paralleled the effect on flour yield (Fig. 5). A slight increase in ash content was observed in flour milled from soaked and dried groats (Fig. 12), while roasted groats gave flours with lower ash contents (Fig. 13).

3.3.3. Bleaching Process

Owing to the unpleasant dark brown color of canaryseed groats which may limit their utilization as intact seeds, a bleaching process was developed to improve the color of seed coat. A four-factor two- level full factorial experiment was conducted on canaryseed groat to optimize bleaching process conditions, i.e. the conditions that produce brighter and more pleasant seed. The factors and levels studied include concentration of hydrogen peroxide (0.5 and 1.0%), temperature (80 and 100° C), time (1 and 2 min) and pH (9 and 11). Sixteen treatment combinations were run in 4 replicates. The bleached seeds were rinsed with tap water, then wiped and dried at 45°C overnight.

The average Hunterlab color scores of bleached seeds are presented in Table 9. A treatment combination of 1% hydrogen peroxide, at a temperature of 80°C, and; pH 11 for 1 min or 2 min resulted in a brighter and more appealing color, having the highest L-, a- and b-values and the lowest total color difference (ΔE). Statistical analysis showed significant influences for main effects and 2-, 3- and 4-way interactions on L-value and ΔE. The a- and b-values were significantly influenced by main effects and 2- and 3-way interactions. The appearance of raw and bleached canaryseed groats are presented in Fig. 14.

3.3.4. Roasting Process

Roasting of canaryseed is an important process in the utilization of intact groats in order to enhance grain taste and palatability. Raw and bleached canaryseed groats were roasted at two temperature levels (250 and 300°C) for two different times (1 and 2 min). A two-factor two-levels full factorial experiment (four treatments) was run on raw and bleached canaryseed groats with duplication. The roasted seeds were evaluated based on seed color and taste. Data in Table 10 show that the roasting process darkened the seed, with bleached roasted seeds having whiter and brighter color compared to raw roasted seeds. In both cases (raw and bleached), statistical analysis showed significant influences for main effects and interactions on L-, a- and b-value and ΔE. Roasting of canaryseed groats at 300°C for 1 min improved taste, but a longer time (2 min) resulted in burnt taste. In a separate experiment, the groats were roasted at 350°C for 30 sec to study the effect of high temperature/short time treatment comparted to the aforementioned treatments. A similar taste and color was obtained with the latter treatment compared to 300°C/1 min treatment.

3.4. Characteristics That Determine Canaryseed Quality

3.4.1. Physical properties

The hairless canaryseed cultivar 'CDC Maria' and the hairy cultivar 'Keet' were obtained from field trials grown at Saskatoon. The grains were cleaned, dehulled and kept for analysis. The hull-free grains or groats were ground into wholemeals or roller-milled into flours and brans. CWRS wheat cultivar 'Katepwa' was grown side by side with canaryseed as a check.

The physical properties of hulled and dehulled canaryseed (groats) from hairless and hairy cultivars are given in Table 11. The CWRS wheat was included as a check and for comparison purposes. Canaryseed is small- elliptical-grains having seed length of 5.1 and 3.9 mm (average of ten seeds from each cultivar) for hulled and dehulled grains, respectively. The seed width averaged 2.0 and 1.6 mm for hulled and dehulled seeds, respectively. Both canaryseed cultivars were similar in seed shape and size. The shape and size of canaryseed would be crucial factors in selecting and/or designing equipments for cleaning and dehulling processes. The CDC Maria had slightly heavier grains than Keet variety. The average CDC Maria canaryseed groat was 6.2 mg compared with 5.8 mg for Keet cultivar. Compared to wheat kernel, canaryseed groat was about two-third of wheat kernel length and one-half of its width. Based on the kernel weight, canaryseed groat ,however, was about only one-sixth of wheat kernel weight. The elliptical shape and smaller size of canaryseed require certain means in cleaning and dehulling when considering canaryseed for human consumption.

The test weight of hulled canaryseed was lower than that of CWRS wheat by about 11% for CDC Maria and 18% for Keet. Removal of the hulls increased test weight which became fairly similar

to CWRS wheat. The hardness of canaryseed groats and wheat kernels was measured using the grinding time method. This method failed to measure canaryseed hardness where the grinder was plugged due to the relatively high content of oil and to the softness character of canaryseed. The color of canaryseed hulls is yellow which is more pleasant than the dark brown color of the seed coat. This indicated by L-, a- and b-values in which canaryseed groat exhibited lower values than hulled canaryseed and wheat grains.

3.4.2. Compositional properties of canaryseed groats

The major constituents of CDC Maria canaryseed wholemeal in comparison with Keet canaryseed and CWRS wheat are presented in Table 12. CDC Maria had chemical composition profile similar to Keet. But, it was slightly higher in starch content and lower in total dietary fiber. Canaryseed groat contained a similar level of starch to CWRS wheat, but was higher in protein and fat and lower in total dietary fiber. This unique composition of canaryseed groats could make the seeds another alternative crop for animal feeding.

The mineral and vitamin compositions of wholemeals of both canaryseed cultivars and CWRS wheat are reported in Table 13. Both canaryseed cultivars were similar in mineral composition which was richer than that of wheat. Canaryseed had higher levels of phosphorus, sulfur, magnesium, calcium, iron, manganese and zinc. For instance, CDC Maria contained higher concentrations of phosphorus, calcium and iron than those in wheat by about 32, 50 and 35%, respectively. Three B-vitamins were determined in canaryseed and wheat wholemeals. Canaryseed contained higher level of thiamine and lower concentration of niacin compared to wheat, riboflavin content was similar in

both grains.

3.4.3. Physical and chemical properties of canaryseed flours

The hull-free grains or groats were tempered to 14% moisture content for 16-18 hr and milled on a Brabender Quadrumat Jr. flour mill. CDC Maria yielded flour slightly higher than Keet at extraction rate of 76% versus 74% for Keet, while wheat had a flour yield of 72% (Table 14). All grains possessed recovery higher than 98% indicating trivial loss during milling process. The colors of canaryseed milled products were measured and compared with wheat flour and bran (Table 15). Canryseed flours were slightly darker than wheat flour as indicated by lower L-values and total color difference (ΔE) scores. Furthermore, canaryseed flours contained lower redness and higher yellowish colors. Also, canaryseed brans were darker than wheat bran having lower L-, a- and b-values and higher ΔE scores.

Fractionation of canaryseed groats into flour and bran caused some changes in the composition of these fractions. Starch was concentrated in to the flour fraction and fat separated partially into the bran fraction, while protein was slightly higher in bran fraction (Table 16). The CDC Maria and Keet flours and brans exhibited slight differences in their composition. Compared with wheat flour, CDC Maria contained lower concentrations of starch, total dietary fiber and sugars, but higher contents of protein and fat. For example, CDC Maria flour had 66% starch, 20% protein and 6% fat comparted to 74%, 14% and 1% in wheat flour, respectively. On the other hand, CDC Maria bran fraction possessed higher levels of starch, fat and total ash than those of wheat bran, but lower concentrations of total dietary fiber and soluble sugars. Protein content was somewhat similar in

canaryseed and wheat brans.

3.4.4. Physicochemical properties of canaryseed flours

Based on our previous studies on canaryseed cultivar Keet, canaryseed flour proteins showed the potential to produce high-viscous dough. The rheological properties of canaryseed flours from CDC Maria and Keet were measured and compared to CWRS wheat flour (Table 17). The major storage proteins in canaryseed were found to be prolamins (alcohol soluble proteins), constituting 45.5% of total proteins (Abdel-Aal et al. 1997a). The total prolamin and glutelin (gluten-forming proteins) constituted 78% of the total canaryseed proteins. The prolamin to glutelin ratio in canaryseed proteins of 1.4 was higher than that of 1.0 in wheat proteins.

The mixograph characteristics of canaryseed flours was measured on a mixograph interfaced with an IBM computer. The system was controlled by a software Mixsmart. Compared with CWRS wheat flour, canaryseed flour produced a weak dough as indicated by mixograph test. The development time of canaryseed flour-water mix was slightly lower than that of wheat flour, while the peak value (the peak time as a percentage of the full scale, torque %) was markedly lower indicating a smaller dough mixing resistance. Also, the mixograph curve slope of canaryseed dough was higher than that of wheat showing low tolerance and high sensitivity to mixing time. The integrated area of canaryseed dough mixographs was smaller than that for wheat indicating lower work required to developing the dough or a dough weakness.

The shape of farinograph curves of canaryseed flour-water systems indicated a weak flour in

which a rapid build up in dough consistency to a sharply defined peak was occurred followed by a relatively rapid breakdown. Farinograph curves of canaryseed cultivars CDC Maria and Keet and CWRS wheat cultivar Katepwa are presented in Fig.17. This paralleled with the obtained data by the mixograph test. Despite the higher content of protein in canaryseed flour than wheat flour, the amount of water taken up by canaryseed flour was lower than that of wheat by about 11% absorption units. Moreover, the rate of water taken up by canaryseed flours and their mixing time were significantly lower than those of wheat flour. However, the stability of canaryseed doughs was slightly lower compared with wheat flour. Also, canaryseed flour was weaker than wheat flour as indicated by higher values of mixing tolerance index.

The visco/amylograph characteristics of canaryseed and flours were measured on 14% slurries using a Brabebder visco/amylograph. The pasting temperature of canaryseed flour averaged 82 °C which was much higher than that of wheat flour (63 °C). There were slight differences among canaryseed and wheat flours in terms of peak viscosity and peak temperature. CDC Maria flour slurry had viscosity of 720 BU comparted to 710 BU for wheat slurry. The peak temperatures of canaryseed and wheat flour slurries occurred at 95 °C after holding the slurries for 6 and 2 min, respectively. Abdel-Aal et al (1997b) found that the pasting temperatures of starch isolated from canaryseed cultivar Keet grown at three locations ranged from 87 to 90 °C. They also reported that the peak viscosities of canaryseed starch pastes were intermediate between those of wheat and corn starch pastes, but were reached well after the 95 °C holding period was initiated.

Sedimentation test is a good predictor for estimating the strength of wheat. Canaryseed flour

was subjected to sedimentation test in order to measure its strength. Based on our results, canaryseed flour was very weak having very low sedimentation volume compared with wheat flour. On the other hand, canaryseed flour contained very small starch granules (Abdel-Aal et al. 1997b) which remain suspended in the solution during the sedimentation test. This indicated by a non-clear solution in the case of canaryseed flour even when standing overnight.

Falling number is a measure of the viscosity flour slurries, with high values being predictive of low α-amylase activity. CDC Maria canaryseed flour had a 23% lower falling number than CWRS wheat. Keet canaryseed flour had an intermediate falling number value between CDC Maria and wheat. Further evaluation on the CDC Maria coming crops will indicate if this a crop character or due to harvesting conditions.

Generally speaking CDC Maria canaryseed flour exhibited dough-forming characteristics. Its dough was very weak as indicated by mixograph, farinograph and sedimentation tests. The flour viscosity was somewhat similar to wheat in spite of higher α-amylase activity. These findings suggest that canaryseed flour could have potential in cookie and biscuit applications or in blending with wheat flour to produce a variety of wheat products.

3.4.5. Antinutrient composition of canaryseed groats

In developing canaryseed as a crop for human consumption and animal feeding, natural antinutritional and phytochemical compounds need to be determined. A survey on these compounds particularly in canaryseed forage and cereal crops indicates the presence of phytate, phenols, tannins,

trypsin inhibitor, amylase inhibitor, glucosides and alkaloids. The genus *Phalaris* was found to contain a wide range of indole alkaloids such as tryptamine, β-carboline, gramine and their derivatives and hordine, a phenolic alkaloid. The alkaloids are mainly found in the plant leaves. Dhurrin, a toxic cyanogenic glucoside, was found in the seedlings of sorghum. The antinutritional and phytochemical compounds may be found in many plants at different levels, but their function in the plants is still questionable, most likely protection against predation. The detrimental effects of these compounds on human health is also debatable. Recent studies indicate that antinutrients and phytochemicals having both adverse and beneficial health effects in humans.

Phytate

Phytic acid is found in the cotyledon of legumes and oilseeds or in the bran of cereal grains. Phytate are considered as anitnutrient due to its role in chelating mineral elements such as calcium and zinc in human body. On the other hand, phytic acid was reported to have some potential beneficial effects such as its ability to lower blood glucose response to starchy foods, and its role in reducing plasma cholesterol and triacylglycerols and cancer risk. Canaryseed groats were found to contain relatively higher levels of phytate compared to wheat. CDC Maria canaryseed possessed the highest concentration at 18.8 mg/g versus 10.7 mg/g in wheat (Table 18). Keet canaryseed still contained high level of phytate of 17.5 mg/g. Removal the brans, markedly reduced phytic acid in the flour fractions of all grains. CDC Maria canaryseed bran fraction contained a higher level of phytate (32.9 mg/g) compared to 21.7 mg/g in wheat bran.

Phenolic Compounds

Phenolic compounds are present in a variety of chemical forms in many plants. The antinutritional properties of Phenolics refer to their astringency and reducing the availability of certain minerals and amino acids. On the other hand, phenolic compounds have antioxidant activity which controls the oxidation of lipids. Total phenolics in canaryseed products were determined by the Prussian blue spectrophotometric method of Price and Butler (1977). Condensed tannins were also determined in canaryseed and wheat grains using the vanillin assay as described by Price et al. (1978). Catechin was used as a standard phenolic compound in Prussian blue and vanillin assays and the phenolic compounds are expressed as catechin equivalent. Canaryseed groats were found to have total phenolic content similar to wheat, averaging 0.84 mg/g (Table 18). After milling, total phenols mainly concentrated in the bran fractions, particularly in wheat bran. Canaryseed flours, however, still contained higher concentrations of total phenolic compounds. No detectable amount of tannins was measured in canaryseed and wheat and their milled products.

Enzyme inhibitors

Trypsin and amylase inhibitors are found in raw cereal and legume grains. These enzyme inhibitors have nutritional implications in human diets. Trypsin inhibitor activity was determined by a spectrophotometric method (Kakade et al. 1974) using benzoyl-DL-arginine-p-nitroanilide (BAPA) as a substrate and 2X crystallized trypsin enzyme. One trypsin unit is defined as an increase of 0.02 absorbance units at 410 nm per 10 mL of the reaction mixture under the test conditions. Trypsin inhibitor activity is expressed in terms of trypsin units inhibited (TIU) per mg sample. Different volumes of trypsin inhibitor extracts were used and it is plotted against TIU to obtain a negative linear

correlation between the inhibitor volume and TIU. The extrapolated value of the inhibitor volume which produce 0.0 TIU was used to calculate TIU per mg sample. Soybean was included as sample check due to its high activity of trypsin inhibitor. Canaryseed and wheat grains showed low activities of trypsin inhibitor, averaging 0.51 TIU/mg compared to 30.26 TIU/mg in soybean (Table 18). Removal of the branny material from the grains reduced trypsin inhibitor activity by about one-third. The trypsin inhibitor activity incearsed in the bran fractions by about 18% on average.

Amylase inhibitor activity was measured in canaryseed and wheat grains using soluble starch as a substrate and pure α-amylase with and without the inhibitor extract (Bernfeld 1955 and Mulimani and Supriya 1993). The resultant reducing sugars were then determined by adding 3.5-dinitrosalicilic acid and the absorbance of the color complex was measured at 540 nm. A sample blank was carried out to eliminate any reducing sugars left in the inhibitor extracts. One unit of enzyme activity was defined as 1 μg of maltose under the assay conditions (5 min, 37 °C). One unit of inhibitory activity is the amount of inhibitor that inhibited one unit of amylase. Canaryseed and wheat grains had similar activities of α-amylase inhibitor (Table 18). After milling they behaved slightly different. In the case of canaryseed, α-amylase inhibitor was concentrated in to the flour fractions, while it was concentrated in the wheat bran fractions.

Alkaloids

Alkaloids are nitrogen containing organic compounds which can be potentially toxic. They are found in some species and families of higher plants particularly in leguminosae as byproducts of plant metabolism, as a reservoir for protein synthesis or as protective materials. A variety of alkaloids

have been found in reed canarygrass which can be grouped into phenol (hordine), indole (gramine, tryptamine) and β-carbolines (trem 1987). These alkaloids were determined in canaryseed groats and their milled products by gas liquid chromatography as described by Duynisveld et al (1990) with some modifications. The trimethylsilyl alkaloid derivatives were analyzed on a Hewlett-Packard Model 5890 gas chromatograph series II equipped with GC/SFC autoinjection 7673, WCOT DB-5 capillary column and flame ionization detector. A calibration standard GLC chromatogram of trimethylsilyl derivatives of alkaloids is presented in Fig. 16. Canaryseed groats and their milled fractions were found to have no detectable levels of the above mentioned alkaloids. However, there were some other unidentified peaks which expected to be some other types of alkaloids. Later, these peaks were identified by GLC-MS which were trace amounts of fatty acids. Based on these results, it seems that canaryseed groats did not contain alkaloids. To confirm this result another technique using high-performance liquid chromatography was used to determine alkaloids (Muir et al 1992). A Waters liquid chromatograph equipped with Waters 600 controller, 600 pump, in-line degasser and dual λ absorbance detector was used. The Millennium chromatography manager version 2.15.01 software was used. A Supelcosil LC-18-DB (25 cm x 4.6 mm) column was used for the determination of alkaloids. The column flow rate was 1 mL/min using gradient solvent system as described by Muir et al (1992). Detection was at 270 nm. A standard solution of gramine, tryptamine and β-carboline 5 mmole was used for calibration. A calibration standard HPLC chromatogram of alkaloids is presented in Fig. 17. Again, no alkaloids were detected in canaryseed groats or in their milled products. Also, samples of canaryseed products were spiked with pure alkaloids and analyzed by GLC and HPLC. The obtained results indicate the absence of hordine, gramine, tryptamine and β-carboline in canaryseed and its products.

Dhurrin, a toxic cyanogenic glucoside, was also determined in canaryseed products using the method described by Gorz et al (1986). No detectable concentration of dhurrin was found in canaryseed and its milled products.

Phenolic acids

Phenolic acids were measured in order to complete the list of antinutrient components in canaryseed groats. Phenolic acids can be divided into three categories: soluble-free, soluble-esterified and insoluble-bound acids. Phenolic acids were found to have beneficial effects as antioxidants, but they were also associated with enzymatic browning and off-flavor in food products. Phenolic compounds have also been shown to reduce the digestible energy in forages. The three forms of phenolic acids were analyzed in the meals, flours and brans obtained from canaryseed and wheat using high performance liquid chromatography (HPLC) as described by Hatcher and Kruger (1997) with some modifications. Seven phenolic acids including protocatechuic, vanillic, caffeic, syringic, coumaric, ferulic and sinapic were used as standards in addition to p-hydroxybenzoic acid as an internal standard.

Small concentrations of free phenolic acids were found in canaryseed and wheat, averaging 1.0 mg/100g (Table 19). Sinapic was the major soluble free phenolic acid in canaryseed, while ferulic acid was dominant in wheat. In canaryseed there were two unidentified major peaks with retention times of 3.4 and 4.1 min. These two components separated at earlier retention times on the HPLC column than known phenolic acids, indicating that they could be derivatives of benzoic acid having high polarity or more free hydroxy groups. After milling, free phenolic acids concentrated into the

bran fractions, while the flour fractions had low levels. Free phenolic acids constituted 2.2% of the total phenolic acids in CDC Maria canaryseed wholemeal compared to 0.9% in wheat wholemeal.

After hydrolysis, the released phenolic acids from the esterified fraction in canaryseed and wheat occurred at higher concentrations than free phenolics, with ferulic being the dominant phenolic acid in all milled products (Table 20). The soluble esterified phenolic acids comprised 7.6% and 2.6% of the total phenolic acids in canaryseed and wheat wholemeals, respectively. Fewer number of insoluble- bound phenolic acids were found in both grains with ferulic acid occurred at very high concentration, while sinapic and coumaric acids were present at small concentrations (Table 21).

Insoluble-bound phenolic acids represented 90.3-93.4% of total phenolic acids in canaryseed and 85.4-96.6% of the total in wheat products. The data also show that phenolic acids (mostly ferulic acid) are concentrated in the bran in a bound form, and would have minimal effects on food products made from flours. There were no major differences in phenolic acid contents of canaryseed meals obtained from a hairy yellow-seeded experimental line (Table 22) as compared to CDC Maria or Keet (Tables 19-22).

Heavy metals

Fifteen heavy metals including nutritive and toxic ones were determined in samples of hairless canaryseed (CDC Maria), hairy canaryseed (keet) and wheat (Katepwa) obtained from ten sites in Saskatchewan (Table 23). There were no significant differences between canaryseed cultivars and wheat grains in toxic metal contents, except for nickel averaging 2.66 mg/kg for hairy canaryseed and

2.27 mg/kg for hairless canaryseed compared to 3.4 mg/kg for wheat. Copper and zinc, that are considered as nutritionally important microminerals, were significantly higher in CDC Maria compared to hairy canaryseed and wheat.

Mycotoxins

Aflatoxins and vomitoxins were analyzed in hairless canaryseed (CDC Maria), hairy canaryseed (Keet) and wheat (Katepwa) grown adjacent at ten locations in Saskatchewan by the Grain Research laboratory, Canadian Grain Commission, Winnipeg, MB. The three crops were found to be free from vomitoxins within the limit of ELISA technique which is 0.5 ppm. A certificate of analysis is attached in Appendix 1. Canaryseed and wheat grains were also found to contain similar levels of aflatoxins being less than 5 ppm. A certificate of aflatoxin analysis is attached in Appendix 2.

3.4.6. Yellow pigments

As we mentioned earlier canaryseed flours contained lower redness and higher yellowish colors as indicated by Hunterlab color scores. This indicates that canaryseed may contain high concentration of yellow pigments. Yellow pigments in canaryseed, wheat and durum wholemeals and their milled products were determined by the AACC (1995) Method 14-50 using water saturated n-butanol as a solvent. CDC Maria and Keet canaryseed flours contained the highest concentration of yellow pigments averaging 18.1 mg/kg compared to 2.7 and 6.4 mg/kg in wheat flour and durum semolina, respectively. Canaryseed brans contained lower concentrations of yellow pigments than wholemeals or flours, but still relatively higher than wheat bran. The high content of yellow pigments

in canaryseed groat and its products would have potential vitamin A activity or not depending on the types of pigments present (Table 24).

3.5. Component-Separation Process

Based on the composition and characterization of canaryseed components (starch, protein and oil), they appear to carry promising potentials in food and non-food industries. A sequential ethanol alkaline wet milling process was developed and evaluated in separation of canaryseed components. The process showed a promising potential based on component yield and purity. Data in Table 25 indicate that 97% of starch was extracted in crude form, while 90% of starch was isolated in a pure form. Approximately 83% of crude protein was isolated (Table 26) compared to 88% for crude fiber (Table 27). Ethanol was used as environmentally friendly solvent which extract only 70% of lipids in canaryseed groats (Table 28). Washing with alkaline solution was applied to the pellets after oil extraction (alkaline washing after oil extraction, AWAOE) or after coarse fiber separation (alkaline washing after coarse fiber separation, AWAOE) or after fine fiber separation (alkaline washing after fine fiber separation, AWAOE) to give treatment 1, 2 and 3, respectively. Treatment 3 yielded the best extraction efficiencies for all components.

3.6. Uses of canaryseed components

3.6.1. Component Separation Process

To evaluate individual components in particular end-uses, treatment 3 which had the best extraction efficiencies for all components was used to isolate canary seed components. Ethanol was used as the solvent and washing with alkaline solution was applied to the pellets after fine fiber

separation.

3.6.2. Canaryseed flour

CDC Maria and CY 184 were tempered to 14% moisture and milled into flour with a Brabender Quadrumat Jr. Roller Mill. The flour yield was 79% for CDC Maria, 74% for CY184 and total recovery was over 97% in all. Bread from canaryseed flour had very low loaf volumes, dense, heavy crumb and had a unique off-flavor. Colors of canaryseed grains which were dark brown or yellow, affected flour color resulting in a dark greenish color of the bread.

Cookies from canaryseed flours were very crunchy in texture and had good spread and no off-flavor. Cookie from Cy184, a yellow seed line, had a favorable yellow in surface color and interior color while CDC Maria (dark brown seed) had a light greenish yellow color and tiny dark specs in cookies prepared from its flour.

3.6.3. Protein and Oil

Protein

Protein isolates are utilized as nutritional supplements and as functional additives in a wide range of foods. Canaryseed protein was peptized by a consecutive series of solvents according to the classical Osborne procedure (Table 29). Canaryseed meal was defatted with hexane prior to the successive protein extraction. Canaryseed protein was less soluble in water and salt solution but more soluble in ethanol (70%). Pure protein isolate was obtained and protein recovery was over 75%. The color of the isolated protein was light brown which might limit its use to darker food preparations.

The value of isolated protein is dependent on its color, a lighter color being preferred as it allows incorporation into a wide range of foods without observable effects on their appearance.

Glutamic acid was the major amino acid and especially, tryptophan, was high in canaryseed protein isolate. Since the use of protein as food ingredients is based on their functionalities, functional properties of canaryseed protein isolates were investigated to determine the potential of canaryseed protein product in food ingredients. Canaryseed protein isolate was found to have less water binding capacity but higher fat absorption and foaming capacity than those of soy protein isolate. Emulsifying activity and emulsion stability were similar to that of soy protein while protein digestibility was slightly lower in canaryseed. Acylation of canaryseed protein isolate increased its water binding capacity and digestibility.

Oil

Canaryseed oil was isolated as a by-product during the sequential ethanol alkaline wet milling process. The major fatty acids in oil extracts from canaryseed groats were linoleic ($C_{18:2}$), oleic ($C_{18:1}$) and palmitic (C_{16}) acids. There were no significant differences in fatty acid composition of oil-hexane solubles extracted by the different treatments during the sequential ethanol alkaline wet milling process.

3.6.4. Starch

The uses of starch is to improve viscosity of foods. The thickening and stabilization are important functional properties of food starches. The clarity of starch paste is another important

attributes in its uses. Native starches are often modified to improve their functional properties to facilitate their uses in the food industry. Properties of starches vary with sources of starches and can be altered by chemical modification of the granules.

Canaryseed starch consist of small granules which has the potential uses as a natural stabilizer in food emulsions. Native canaryseed starch was applied as a stabilizer in oil-water emulsions such as mayonnaise and salad dressing. Mayonnaise containing canaryseed starch as an ingredient had high viscosity and showed very good emulsion stability at low temperature for several days. Mayonnaise with canaryseed starch compared to the control (no starch) was whiter in color.

Processing of noodles made from canaryseed starch was attempted and there appears to hold promise. Canaryseed starch noodle had a good, opaque, glassy, and transparent appearance. The property of canaryseed starch noodles needs to be investigated further to explain its structural changes during cooking and to improve the quality of its end product.

Native canaryseed starch had a very high gelatinization temperature (≈95°C) which was reduced to 58°C (cross-linked and hydroxypropylated) and 55°C (hydroxypropylated) by modification (Fig.18). Cross-linking and hydroxypropylation of canaryseed starch increased peak viscosity and setback in the amylograph profile. Hydroxypropylated starch had lower pasting temperature, higher peak viscosity and breakdown than double modified starch (cross-linked and hydroxypropylated).

Clarity of paste from canaryseed starch was much improved by the modifications (Fig.19). Hydroxypropylated starch had higher paste clarity as expected. It is typical that cross-linking reduces the paste clarity and stability at low temperature. The order of canaryseed starch pastes ranked by decreasing clarity is hydroxypropylated > cross-linked and hydroxypropylated > native starch.

Cold storage stability was higher in modified starches. Paste from native canaryseed starch (6%) had over 70% water separation with 4 cycles of freeze-thaw while paste from modified starches (6%) had approximately 30~49% separation at over 10 cycles. This could be a good indicator that canaryseed starch with some degree of modification can be used as an ingredient binder in frozen foods.

Starch succinate derivatives cause lower gelatinization temperatures, high thickening power and good filming properties. Cold-water-soluble starch succinates have been successful in replacing gum arabic as a stabilizer in the beverage industry. Succinylated canaryseed starch had lower gelatinization temperature and higher peak viscosity than native starch. Emulsion made with succinylated canaryseed starch showed higher stability at room and low temperature (4 °C) than that made with commercial stabilizer products such as Gum arabic and Purity gum (modified corn starch). Paste from succinylated canaryseed starch also exhibited excellent freeze-thaw stability. Succinylated canaryseed starch could be used as a stabilizer replacing gum arabic in oil-water emulsions including beverage emulsions, flavors, salad dressing, creams, etc.

To facilitate the utilization of canaryseed starch in the non-food industry, it was cationized

to improve its viscosity and to reduce its pasting temperature. Cationized starches are widely used in the paper industry as a binding agent. Cationized canaryseed starch was four times higher in peak viscosity and had a much lower pasting temperature (49.5 °C) than those of native canaryseed starch (95 °C)(Fig. 20).

3.6.5. Fiber

Fiber extracts from CDC Maria, fine and coarse fiber from 3 to 5%, was mixed with commercial flour. Loaf volume was slightly decreased by increasing the fiber contents of the flour. There were no significant difference in crust color between bread from control flour and flour blended with canaryseed fiber extracts. Crumb texture was slightly decreased in bread containing fiber compared to control (non-fiber) bread. Color differences in bread crumb containing fiber was noticeable. Coarse fiber resulted in a light grey color and visible dark brown particles in the bread crumb while bread containing fine fiber had a greyish color but no visible dark particles in the crumb. Higher fiber content in flour resulted in increasing greyness and coarse grain in bread crumb color.

4. Indications for further development

Since canaryseed components held a promise for use in food and non- food applications, the development and quality evaluation of their end products requires further investigation..

(c) Personnel

Dr. Abdel-Aal left our employ in order to join AAFC in Guelph, Ontario. Dr. Heesoo Han replaced Dr. Abdel-Aal. Lanette Ehman was on maternity leave from September, 1999 to March,

2000. Dr. Heesoo Han was on maternity leave from August, 2000 to February , 2001. Jason Ram was hired to conduct the poultry feeding trials and toxicology trials.

Dr. E-S.M. Abdel-Aal (July 1, 1997 – December 30, 1998)-50%

(Res. Scientist) (January 1, 1998 – June 30, 1999) - 33%

Dr. Heesoo Han (June 1, 1999 – March 31, 2001) - 33%

(PRA)

Lanette Ehman (July 1, 1997 – September, 1999; March 1- June 31, 2000)-100%

(Technician) (July 1, 2000 - March 31, 2001) - 60%

Sandy Meacham (September 1, 1998 –August 31, 1999) -50%

(Technical Assistant)

Warren Schatz (September 1, 1999 – March 31, 2000) -100%

(Technical Assistant)

Janet Colbourn (May 1 – November 3, 1999) – 50%

(Summer Assistant, then Technical Assistant)

Jason Ram (April 1, 1999 – September 30, 2000) – 100%

(Technician)

Kalavathi Karthikeyan (October 1, 1997 – April 30, 1998) - 100%

(Technician)

Ginette Ratte (January 15-31, 1998) - 100%

(Technical Assistant)

Frederick Hill (February 1 - March 31, 1998) - 10%

(Casual labourer)

Mireille Arsenault (April, 1998 - October 31, 1998) - 50%

(Technical Assistant)

Anna Caldwell (May 1, 1998 – August 31, 1998) - 50%

(Summer Assistant)

Carla Van der Laan (September 1, 1997 – December 31, 1997) - 50%

(Technical Assistant)

James Cardinal (August 1, 1997 – September 30, 1997) - 100%

(Casual labourer)

(d) Equipment- Nil

(e) Project photos- Nil

(f) AFIF acknowledgment – at field days.

Presentations:

IHARF Update, January 28th, 1998.

Soil and Crops Update, February 20th, 1998.

(g) Project public information materials

Western Crop Production Show (January 1999)

(h) Expense statement

To follow.

Pending commitments: Nil

(i) Deliverables for evaluation

Variety in commercial stream.

Trademark being implemented for glabrous canaryseed by the Canadian Special Crops Association.

Official Notification to Health Canada to have canaryseed utilized for human consumption.

Field evaluation of first glabrous, yellow-seeded line. This will be the prototype for human consumption.

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Table 1. Agronomic performance of yellow-seeded canaryseed lines grown at two sites (Kernen and Seed Farms) in 1997

Line	Grain yield (kg/ha)	Heading (days)	Maturity (days)	Height (cm)	Test Wt (kg/hl)	!000 kernel Wt (mg)
1 Keet	2029	53.3	91.8	91	64.7	7.4
2 Elias	2152	52.5	88.2	90	69.6	7.8
3 CDC Maria	1850	53.2	90	90	72.7	7.9
4 C96016	1953	53.3	88.8	91	71.9	7.7
5 C96020	1921	53.2	89.7	90	72.6	8
6 C96032	1947	53.2	89.8	90	72.9	7.9
7 CY179	2150	56.5	93.3	94	65	7.9
8 CY180	2161	57	97.5	95	66.3	7.8
9 CY181	2159	52.7	89.8	88	66	7.5
10 CY182	2317	56	91.8	92	64.8	7.6
11 CY183	2249	57	94	93	64.5	7.6
12 CY184	2096	52.8	89	91	64.7	7.5
13 CY185	2046	52.7	90.5	91	66.3	7.8
14 CY186	2340	56.5	94	92	66.1	8
15 CY187	2299	57.3	95.7	94	65.3	8
16 CY188	2285	57	95	95	66.3	8.1
17 CY189	2199	56.8	93.2	94	65.1	7.9
18 CY190	2256	56.7	94	92	65.9	7.8
19 CY191	2280	56.5	94.2	93	63.8	7.8
20 CY192	2259	52.7	90.3	90	65	7.7
21 CY193	1886	52.8	89.7	88	66.1	7.6
22 AGPR01	2161	55.5	91.2	101	66.6	7.7
23 AGPR02	2168	53	89.5	94	69.7	7.9
24 CY15	1960	52.7	90	89	65.2	7.2
25 EGYPT1	1979	51.7	89.5	86	68.4	8

CV(%) Seed Farm = 6.5 and Kernen Farm = 8.0.

Table 2. Comparison of C96020 glabrous canaryseed with CDC Maria in 1996 and 1997.

	Soil zone			Average
	Brown	Dark brown	Black	
	Grain yield (kg/ha)			
CDC Maria	1754	1847	1177	1702
C96020	1627	1944	1095	1742
Keet	1983	2050	1176	1868
# of sites	1	7	2	10

Table 3. F2 Segregation for hull pubescence in canaryseed, pooled over populations

	Number of Plants			
	Hairy	Glabrous	X^2	Probability
Five populations (greenhouse)	1798	554	2.625	0.25-0.10
Six populations (field)	6009	2069	1.617	0.25-0.10

Table 4 . F2 Segregation for seed colour in canaryseed, pooled over populations

	Number of Plants			
	Brown	Yellow	X^2	Probability
One population (greenhouse)	287	116	3.077	0.10-0.05
Two populations (field)	815	270	0.013	0.95-0.90

Table 5. Agronomic performance of elite canaryseed lines tested In 1999 and 2000 in replicated trials

	Yield	HD	MA	HT	LBL	LDG
	%	---------- +/- Maria ----------				
1 CDC	100.0	0.0	0.0	0.0	0.0	0.0
2 C99005	102.0	0.8	0.1	-0.9	0.0	0.0
3 C99018	109.1	-1.6	1.1	1.4	0.1	0.0
4 C99022	105.3	-1.7	1.4	2.5	-0.1	0.0
5 C99024	100.7	-0.9	1.9	0.1	-0.2	0.0
6 C99025	103.2	-0.1	1.8	5.5	-0.3	0.0
7 C99037	110.0	0.4	-0.1	0.7	-0.1	-2.3
8 C99048	109.6	2.1	1.1	-1.3	-0.1	-2.3
9 C99049	109.6	1.1	1.6	-2.5	-0.4	0.0
10 C99050	114.2	2.2	1.6	1.3	-0.7	-2.3
11 C99052	110.0	1.8	2.3	0.1	-0.5	-0.6
12 C99053	107.4	-0.7	1.2	1.2	-0.2	-2.3
13 C99060	109.7	0.0	1.2	-2.2	-0.4	-0.3
14 C99066	105.7	0.4	-0.1	-4.0	0.1	-2.0
# of trials	8	6	5	6	3	3

HD = days to heading
MAT = days to maturity
HT = plant height
LBL = leaf mottle (1-5 rating scale)
LDG= lodging (1-9 scale)

Table 6. Agronomic performance of second cycle breeding material
In replicated trials in 2000.

	Yield Kg/ha	HD d	MAT d	HT cm	LBL 1-5
1 CDC Maria	908	52.1	88.2	90.8	3.3
2	854	53.5	89.1	92.0	3.5
3	947	53.5	89.1	91.1	3.1
4	1025	53.5	87.4	92.5	2.6
5	793	54.6	89.5	93.9	2.8
6	1003	55.5	89.5	92.5	2.9
7	954	54.8	89.1	92.3	3.3
8	1046	55.5	90.2	89.6	3.0
9	1048	53.4	88.5	88.0	3.3
10	1065	53.7	88.6	91.3	2.9
11	1045	54.0	89.4	92.8	3.1
12	1054	54.9	89.3	94.6	3.1
13	779	55.2	89.2	91.6	3.1
14	1000	52.0	87.7	89.7	2.6
15	1103	56.0	88.9	92.8	2.6
16	1093	54.2	89.7	96.3	3.3
17	1040	54.3	89.8	90.4	3.1
18	967	54.9	89.3	95.1	2.8
19	1214	55.2	90.4	86.5	2.4
20	983	53.6	91.5	90.9	2.9
21	909	55.3	90.2	92.7	2.8
22	930	55.4	89.6	92.5	3.1
23	1091	54.1	89.1	93.5	2.9
24	1027	54.2	89.7	95.6	2.8
25	1068	54.2	89.5	93.6	2.9
26	1029	54.2	89.6	95.0	2.9
27	1083	54.4	88.7	94.0	3.5
28	1001	54.8	88.4	95.9	3.0
29	1011	54.8	89.6	95.3	2.6
30	993	54.9	89.8	92.6	2.8
31	1114	55.2	89.2	94.5	3.1
32	960	54.5	89.7	91.3	3.3
33	1077	54.0	88.8	94.8	3.3
34	1107	54.7	89.7	92.6	2.8
35	1145	53.5	89.0	92.4	3.3
36	1020	55.3	90.3	92.9	3.3
N =	3	3	3	3	3

Table 7. Dehulling effectiveness at machine speeds of 700, 900, 1100, and 1300 rpm with flow rates of 0.95, 4.5, and 8.7 kg/min, and a sample size of approximately 500.0g

Speed	Flow Rate	% Broken		% with Hulls		% Dehulled		Dehulling Effectiveness	
(RPM)	(kg/min)	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
700	0.95	4.57 cde	0.78	17.07 cd	1.16	78.23 bc	0.60	0.63 bcd	0.01
	4.48	3.30 ef	0.33	43.80 ab	1.93	52.38 de	1.78	0.16 ef	0.03
	8.70	2.87 f	0.71	51.36 a	0.17	45.74 e	0.82	0.02 f	0.00
900	0.95	5.57 bc	0.16	6.53 e	2.74	88.06 a	2.47	0.80 a	0.04
	4.48	4.43 cde	0.12	23.71 c	1.09	71.61 c	1.31	0.51 d	0.02
	8.70	3.93 def	0.56	38.87 b	11.62	57.26 d	11.28	0.24 e	0.22
1100	0.95	6.14 ab	0.91	2.41 e	0.79	91.31 a	0.06	0.85 a	0.00
	4.48	4.63 bcde	0.10	18.33 c	2.32	76.84 c	2.16	0.61 cd	0.04
	8.70	4.89 bcd	0.54	19.82 c	2.32	75.29 c	2.59	0.58 cd	0.05
1300	0.95	7.30 a	0.53	0.82 e	0.27	91.72 a	0.25	0.84 a	0.01
	4.48	5.93 abc	1.50	7.52 e	3.06	86.41 a	1.40	0.77 ab	0.03
	8.70	5.76 bc	0.78	8.92 ed	0.18	85.24 ab	0.42	0.71 abc	0.06

Means having the same letter in the same column are not significantly different (P> 0.05, n=2).

Table 8. Dehulling effectiveness with pre-treatment of seeds, a machine speed of 1100 rpm, a flow rate of 0.95 kg/min, and a sample size of approximately 500.0g

Treatment	% Broken		% with Hulls		% Dehulled		Dehulling Effectiveness	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Through 2X	7.51 a	0.95	0.29 d	0.12	91.86 a	1.49	0.861 a	0.02
12% Moisture	6.19 a	0.17	2.96 b	0.57	90.19 ab	1.17	0.836 a	0.02
14% Moisture	6.65 a	0.39	1.61 c	0.48	90.83 ab	0.04	0.845 a	0.00
16% Moisture	6.44 a	0.44	1.90 bc	0.28	90.31 ab	0.72	0.843 a	0.01
250C/1 min	7.22 a	0.83	5.53 a	0.60	87.21 c	1.46	0.784 b	0.02
90C/3 min	5.89 a	0.82	5.52 a	0.11	88.62 bc	0.90	0.667 c	0.01
Control	6.14 a	0.91	2.41 bc	0.79	91.31 a	0.06	0.851 a	0.00

Means having the same letter in the same column are not significantly different (P> 0.05, n=2)

Table 9. Effect of Bleaching conditions on Hunterlab color values[a] of hairless canaryseed groats

Treatment combination[b]	L-value	a-value	b-value	Total color difference (ΔE)
0.5/80/1/9	27.0 .19[c]	5.4 .03	8.9 .09	67.1 .52
1.0/80/1/9	27.9 .40	5.8 .07	9.7 .15	66.1 .42
0.5/100/1/9	27.4 .13	5.5 .11	9.0 .55	66.5 .11
1.0/100/1/9	29.7 .21	6.0 .13	10.5 .40	64.4 .52
0.5/80/2/9	26.9 .42	5.5 .12	9.0 .34	67.0 .33
1.0/80/2/9	28.5 .20	6.0 .07	10.0 .22	65.6 .26
0.5/100/2/9	27.2 .29	5.3 .06	8.9 .30	66.9 .73
1.0/100/2/9	29.7 .28	6.0 .08	10.5 .44	64.5 .88
0.5/80/1/11	34.8 .75	8.3 .07	15.1 .36	60.6 .60
1.0/80/1/11	39.0 .90	8.9 .09	17.3 .47	57.3 .63
0.5/100/1/11	32.1 .27	8.2 .04	13.5 .18	62.9 .31
1.0/100/1/11	29.1 .02	7.8 .25	11.5 .43	65.5 .04
0.5/80/2/11	35.3 .40	8.3 .04	15.3 .19	69.2 .85
1.0/80/2/11	37.8 .90	8.9 .05	16.8 .32	58.5 .06
0.5/100/2/11	30.4 .13	8.0 .12	12.3 .21	64.3 .67
1.0/100/2/11	28.8 .17	8.0 .09	11.4 .53	65.8 .97
Control untreated seeds	25.8 .74	4.01 .09	6.7 .32	67.7 .76

[a]L (100 = white, 0 = black); a (+ = red, - = green); b (+ = yellow, - = blue).
[b]Each treatment combination consists of hydrogen peroxide concentration (%), temperature (°C), time (min) and pH, respectively.
[c]Mean ±SD, n=4.

Table 10. Effect of roasting conditions on Hunterlab color values[a] of hairless canaryseed groats

Treatment combination[b]	L-value	a-value	b-value	Total color difference (ΔE)
Raw seeds				
250/1	26.0 ±0.10[c]	4.3 ±0.07	7.3 ±0.08	67.6 ±0.53
250/2	25.8 ±0.11	5.3 ±0.03	7.5 ±0.05	67.9 ±0.10
300/1	26.4 ±0.26	4.9 ±0.07	7.7 ±0.11	67.3 ±0.31
300/2	20.7 ±0.12	4.2 ±0.04	3.9 ±0.11	72.7 ±0.44
Bleached seeds				
250/1	40.4 ±0.29	9.1 ±0.03	17.6 ±0.13	56.5 ±0.51
250/2	38.7 ±0.28	10.4 ±0.08	16.6 ±0.05	57.6 ±0.68
300/1	40.6 ±0.31	9.7 ±0.07	17.5 ±0.11	55.9 ±0.61
300/2	26.9 ±0.38	9.3 ±0.09	9.8 ±0.17	67.5 ±0.48
Control (non-roasted) seeds				
Raw	25.8 ±0.74	4.01 ±0.09	6.7 ±0.32	67.7 ±0.76
Bleached	39.0 ±0.90	8.9 ±0.09	17.3 ±0.47	57.3 ±0.63

[a]L (100 = white, 0 = black); a (+ = red, - = green); b (+ = yellow, - = blue).
[b]Each treatment combination consists of temperature (°C) and time (min), respectively.
[c]Mean ±SD, n=4.

Table 11. Physical properties of canaryseed kernels "CDC Maria" versus "Keet" in comparison with Katepwa CWRS wheat

Property	Canaryseed				Wheat
	CDC Maria		Keet		Katepwa
	Hulled	Dehulled	Hulled	Dehulled	
Kernel size					
Length (mm)	5.1	3.9	5	3.8	5.6
Width (mm)	2.1	1.6	1.9	1.6	3
Kernel weight (mg)	7.2	6.2	6.5	5.8	33.8
Test weight (kg/hL)	71	79.1	65.3	77.8	80.1
Kernel hardness (sec)	-	NA	-	NA	18
Kernel color					
L (100 = white, 0 = black)	46	27.5	47.5	28.3	40.6
a (+ = red, - = green)	4.3	4.3	4.3	4.3	7.3
b (+ = yellow, - = blue)	14.7	7.3	14.4	7.4	13.4
Total color difference (ΔE)	48.9	66.1	53.7	65.3	54.5

NA = not applicable.

Table 12. Compositional properties of dehulled canaryseed and CWRS wheat whole meals (% dry basis)

Constituent	Canaryseed		Wheat
	CDC Maria	Keet	Katepwa
Starch	61.2	59.1	59.8
Protein (N x 5.7)	19.6	20.3	15.3
Crude fat	7.7	8	2.5
Total dietary fiber	5.9	8.3	12.8
Soluble sugars	1.9	1.7	3.1
Total ash	2.1	1.9	1.6
Total constituents	98.4	99.3	95.1

Table 13. Mineral and vitamin contents of dehulled canaryseed and CWRS wheat whole meals (mg/100g dry basis)

Constituent	Canaryseed		Wheat
	CDC Maria	Keet	Katepwa
	Minerals		
Phosphorus	640	590	430
Potassium	385	340	355
Sulfur	305	300	200
Magnesium	200	195	155
Calcium	40	40	20
Sodium	10	10	10
Iron	6.5	5.9	4.2
Manganese	6.3	7.1	5.9
Zinc	3.9	3.5	2.5
Copper	0.2	0.2	0.3
	Vitamins		
Thiamine	0.85	0.79	0.44
Riboflavin	0.16	0.16	0.15
Niacin	0.68	0.89	7.29

Table 14. Roller-milling properties of dehulled canaryseed groats compared with CWRS wheat grains

Property	Canaryseed		Wheat
	CDC Maria	Keet	Katepwa
Flour yield (%)	76.2	73.8	72.1
Bran (%)	23.8	26.2	27.9
Recovery (%)	98.5	99.6	98.8

Table 15. Hunterlab color values of dehulled canaryseed and CWRS wheat milled products

Constituent	Canaryseed		Wheat
	CDC Maria	Keet	Katepwa
	Flours		
L (100 = white, 0 = black)	85.6	85.8	89
a (+ = red, - = green)	-0.08	-0.15	0.51
b (+ = yellow, - = blue)	16.4	16.6	10.6
Total color difference (ΔE)	16.8	17	10.2
	Brans		
L (100 = white, 0 = black)	52.5	55.2	63.9
a (+ = red, - = green)	1.69	1.55	4.9
b (+ = yellow, - = blue)	6.9	7.3	13
Total color difference (ΔE)	41.1	38.5	32

Table 16. Compositional properties of dehulled canaryseed and CWRS wheat milled products (% dry basis)

Constituent	Canaryseed		Wheat
	CDC Maria	Keet	Katepwa
	Flours		
Starch	65.5	67.6	73.9
Protein (N x 5.7)	19.5	18.8	13.9
Crude fat	6.3	6	1.3
Total dietary fiber	1.2	1.3	3.5
Sugars	1.6	1.5	2.9
Total ash	0.8	0.8	0.6
Total constituents	94.9	96	96.1
	Brans		
Starch	35.1	38.3	24.3
Protein (N x 5.7)	21.1	20.4	20.4
Crude fat	13	13	5.9
Total dietary fiber	18.6	17.6	39.7
Sugars	1.9	1.9	5.8
Total ash	7.7	7.6	4.6
Total constituents	97.4	98.8	94.8

Table 17. Physicochemical properties of canaryseed and CWRS wheat flours

Property	Canaryseed		Wheat
	CDC Maria	Keet	Katepwa
	Mixograph		
Peak time (min)	2.6	2.4	2.8
Peak value (%)	36.7	40.3	54.3
Slope (%/min)	0.88	0.87	-2.6
Band width (%)	25.3	32.9	13.9
Area (%Tq*min)	234.8	254.3	329.8
	Farinograph		
Flour absorption (%)	54	54	65
Arrival time (min)	0.5	0.5	1.5
Peak time (min)	2	2	4
Stability (min)	8.5	9.5	9.5
Mixing tolerance index (BU)	65	70	40
	Visco/Amylograph		
Pasting temperature (C)	82.5	81.8	63
Peak Viscosity (BU)	720	695	710
Peak temperature (C)	95	95	95
	Sedimentation volume (mL)		
	6.5	6.3	83.8
	Falling number (sec)		
	477	522	617

Table18. Antinutrient composition of dehulled canaryseed and CWRS wheat and their milled products

Antinutrient	Canaryseed		Wheat
	CDC Maria	Keet	Katepwa
	Whole grain		
Phytate (mg/g)	18.8	17.5	10.7
Total phenols (mg/g)	0.87	0.83	0.81
Condensed tannin (mg/g)	ND	ND	ND
Trypsin inhibitor (TIU/mg)	0.56	0.51	0.47
Amylase inhibitor (AIU/mg)	2.80	2.84	2.66
	Flour		
Phytate (mg/g)	8.3	7.9	5.8
Total phenols (mg/g)	0.83	0.69	0.18
Condensed tannin (mg/g)	ND	ND	ND
Trypsin inhibitor (TIU/mg)	0.31	0.4	0.36
Amylase inhibitor (AIU/mg)	3.01	3.22	2.26
	Bran		
Phytate (mg/g)	32.9	32.1	21.7
Total phenols (mg/g)	2.14	2.13	2.44
Condensed tannin (mg/g)	ND	ND	ND
Trypsin inhibitor (TIU/mg)	0.64	0.59	0.63
Amylase inhibitor (AIU/mg)	2.42	2.12	3.52

ND = not detected.

Table 19. Individual soluble free phenolic acids (mg/100g) in hairless (CDC Maria) and hairy (Keet) canaryseed groats and CWRS wheat and their milled products

Grain	Protoca-techuic	Vanillic	Caffeic	Syringic	Coumaric	Ferulic	Sinapic	Total
Canaryseed, CDC Maria								
Meal	0.13	0.12	0.07	Tr	0.06	0.15	0.42	0.98
Flour	0.11	Tr	Tr	Tr	0.05	0.06	0.1	0.39
Bran	0.48	0.49	0.27	0.05	0.18	0.31	0.96	2.74
Canaryseed, Keet								
Meal	0.15	0.16	0.05	Tr	0.11	0.22	0.68	1.41
Flour	ND	0.09	Tr	Tr	0.09	0.17	0.06	0.47
Bran	0.47	0.43	0.05	0.1	0.17	0.25	0.7	2.17
CWRS Wheat. Katepwa								
Meal	0.14	0.08	Tr	0.08	0.06	0.32	0.29	1.01
Flour	ND	0.33	Tr	Tr	Tr	0.09	Tr	0.47
Bran	0.13	0.36	0.1	0.12	0.07	0.71	0.34	1.84

ND=not detectable. Tr=traces.

Table 20. Individual soluble bound phenolic acids (mg/100g) in hairless (CDC Maria) and hairy (Keet) *canaryseed groats and CWRS wheat and their milled products*

Grain	Protoca-techuic	Vanillic	Caffeic	Syringic	Coumaric	Ferulic	Sinapic	Total
Canaryseed, CDC Maria								
Meal	ND	0.45	Tr	0.12	0.87	1.24	0.67	3.38
Flour	Tr	Tr	ND	Tr	0.14	0.16	0.11	0.49
Bran	ND	1.18	1.49	0.38	1.4	3.12	0.91	8.49
Canaryseed, Keet								
Meal	ND	0.76	0.05	0.13	0.93	1.24	0.15	3.26
Flour	ND	0.61	Tr	Tr	0.12	0.25	0.05	1.05
Bran	ND	1.92	0.14	0.29	1.5	2.86	0.59	7.3
CWRS Wheat, Katepwa								
Meal	ND	0.7	0.06	0.44	0.12	1.11	0.37	2.8
Flour	ND	Tr	ND	0.05	Tr	0.12	0.07	0.26
Bran	ND	1.99	0.1	1.07	0.28	2.41	0.89	6.74

ND=not detectable, Tr=traces.

Table 21. Individual insoluble bound phenolic acids (mg/100g) in hairless (CDC Maria) and hairy (Keet) canaryseed groats and CWRS wheat and their milled products

Grain	Protoca-techuic	Vanillic	Caffeic	Syringic	Coumaric	Ferulic	Sinapic	Total
Canaryseed, CDC Maria								
Meal	ND	ND	ND	ND	5.37	26.76	8.27	40.39
Flour	ND	ND	ND	ND	1.17	4.39	2.11	9.42
Bran	ND	0.22	Tr	Tr	21.21	118.9	19.29	159.6
Canaryseed, Keet								
Meal	ND	ND	ND	ND	5.24	28.54	6.72	40.5
Flour	ND	ND	ND	ND	0.7	4.33	1.78	6.82
Bran	ND	0.84	0.4	0.41	19.31	108.6	16.9	146.5
CWRS Wheat, Katepwa								
Meal	ND	ND	ND	ND	3.14	78.08	23.61	104.8
Flour	ND	ND	ND	ND	0.42	6.17	3.87	10.46
Bran	ND	2.85	0.75	1.89	7.65	229.1	4.92	241.9

ND=not detectable, Tr=traces.

Table 22. Individual soluble-free, soluble-bound and insoluble-bound phenolic acids (mg/100g) in hairy yellow-seeded canaryseed groats

Phenolic compound	Protoca-techuic	Vanillic	Caffeic	Syringic	Coumaric	Ferulic	Sinapic	Total
Free soluble	ND	ND	ND	ND	0.15	0.26	0.54	0.95
Soluble bound	ND	0.18	0.17	0.22	0.39	1.46	0.7	3.12
Insoluble bound	ND	0.31	ND	ND	5.3	29.71	4.82	40.14

ND=not detectable.

Table 23. Statistical estimates of heavy metal contents (mg/kg) of CDC Maria and Keet canaryseed compared with wheat grains

Metal	Keet			CDC Maria			Wheat		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Ag	0.1a	0	0.1-0.1	0.1a	0	0.1-0.1	0.1a	0	0.1-0.1
As	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2	0.2a	0	02.-0.2
Bi	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2
Cd	0.1a	0	0.1-0.1	0.1a	0	0.1-0.1	0.1a	0	01.-0.1
Co	0.29a	0.23	0.10-0.90	0.21a	0.13	0.10-0.40	0.18a	0.16	0.10-0.60
Cu	117.8a	78.6	48.2-329.9	38.0b	15.5	15.2-58.3	24.4b	7.01	13.3-34.1
Hg	0.03a	0	0.03-0.03	0.03a	0	0.03-0.03	0.03a	0	0.03-0.03
Mo	0.23a	0.41	0.10-1.40	0.51a	0.71	0.10-2.20	0.64	0.94	0.10-2.40
Ni	2.66a	1.07	1.00-4.40	2.27a	1.06	0.50-3.60	0.34b	0.16	0.10-0.60
Pb	0.37a	0.42	0.10-1.20	0.21a	0.23	0.10-0.70	0.13a	0.09	0.10-0.40
Sb	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2
Se	2.71a	1.34	1.20-5.50	3.19a	1.96	1.40-7.40	2.08a	0.62	1.40-3.50
Te	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2
W	0.22a	0.04	0.2-0.3	0.2a	0	0.2-0.2	0.2a	0	0.2-0.2
Zn	63.6a	18.1	43.20-108.40	44.78b	12.33	25.30-63.40	32.24c	6.77	22.40-45.80

Means in a row having different letters are significantly different at p = 0.05 and n = 10 sites.

Table 24. Yellow pigment contents of dehulled canaryseed and CWRS and CWAD wheats and their milled products (mg/kg dry basis)

Grain	Product	Pigment content
Canaryseed "CDC Maria"	Whole	15.35
	Flour	18.16
	Bran	12.52
Canaryseed "Keet"	Whole	16.16
	Flour	18.14
	Bran	13.62
Wheat "Katepwa"	Whole	4.64
	Flour	2.69
	Bran	6.52
Durum "Kyle"	Whole	5.42
	Semolina	6.37

Table 25. Yield and extraction efficiency of canaryseed starch isolated by sequential ethanol alkali wet milling process (dry basis)

Type of Treatment	Starch (%)		Yield (g/100g)[a]	Starch extraction efficiency (%)	
	Groats	Isolate		Based on crude starch[b]	Based on pure starch[c]
AWAOE[d]	56.9	93.3	55	96.7	90.1
AWACFS	56.9	92.9	50.6	88.9	82.6
AWAFFS	56.9	94.7	44.3	77.8	73.7

[a]g starch per 100 g canaryseed groats.
[b](starch yield / % of starch in groats) x 100].
[c](g starch in isolate yield / % of starch in groats) x 100].
[d]AWA=Alkaline Washing After: Oil Extraction (OE), Coarse Fiber Separation (CFS) or Fine Fiber Separation (FFS).

Table 26. Yield and extraction efficiency of canaryseed protein isolated by sequential ethanol alkali wet milling process (dry basis)

Type of Treatment	Protein (%)		Yield (g/100g)[a]	Protein extraction efficiency (%)	
	Groats	Isolate		Based on crude protein[b]	Based on pure protein[c]
AWAOE[d]	25.6	78.9	21.3	83.2	65.6
AWACFS	25.6	82.7	21.6	84.4	69.8
AWAFFS	25.6	74.9	17.4	68	50.9

[a]g protein per 100 g canaryseed groats.
[b](protein yield / % of protein in groats) x 100].
[c](g protein in isolate yield / % of protein in groats) x 100].
[d]AWA=Alkaline Washing After: Oil Extraction (OE), Coarse Fiber Separation (CFS) or Fine Fiber Separation (FFS).

Table 27. Yield and extraction efficiency of canaryseed fiber isolated by sequential ethanol alkali wet milling process (dry basis)

Type of Treatment	Total dietary fiber (%)			Yield (g/100g)[a]		Total fiber extraction efficiency (%)	
	Groats	Isolate		Coarse	Fine	Based on crude fiber[b]	Based on pure fiber[c]
		Coarse	Fine				
AWAOE[d]	7.2	6.38	59.6	4.2	2.1	87.5	55.6
AWACFS	7.2	36.3	56	6.1	2.2	115.3	47.2
AWAFFS	7.2	31	15.2	8.2	8.6	233.3	51.4

[a]g fiber per 100 g canaryseed groats.
[b](g total fiber yield / % of fiber in groats) x 100].
[c](g total fiber in isolate yield / % of fiber in groats) x 100].
[d]AWA=Alkaline Washing After: Oil Extraction (OE), Coarse Fiber Separation (CFS) or Fine Fiber Separation (FFS).

Table 28. Yield and extraction efficiency of canaryseed oil isolated by sequential ethanol alkali wet milling process (dry basis)

Type of Treatment	Oil in groats (%)	Yield (g/100g)[a]	Oil extraction efficiency (%)[b]
AWAOE[c]	7.6	5.3	70
AWACFS	7.6	5.1	67.1
AWAFFS	7.6	5	65.8

[a]g oil per 100 g canaryseed groats.
[b](g oil yield / % of oil in groats) x 100].
[c]AWA=Alkaline Washing After: Oil Extraction (OE), Coarse Fiber Separation (CFS) or Fine Fiber Separation (FFS).

Table 29. Protein solubility of canary seed meal by Osborne classification

	%N	% of Total protein solubles
Meal	3.98	--
Water solubles	0.23	5.88
5% NaCl solubles	0.26	6.76
Ethanol (70%) solubles	2.12	53.62
0.2% NaOH solubles	1.02	8.88
Residue[1]		24.86

[1] by difference

(On a Dry Matter Basis)	Diets Containing 80% of Test Ingredient (n=6) CDC Teal	Dehulled CDC	Hulled CDC	Hulled Keet	STD Error
Ingredient (Fecal) AME_n	2303^{C}	3867^{A}	3205^{B}	3292^{B}	121.5
Ingredient Protein (Ileal) Digestibility	86.1	86.4	88.3	86.2	0.75
Ingredient Starch (Ileal) Digestibility	86.0^{B}	97.9^{A}	100.7^{A}	100.4^{A}	1.38
Ingredient Fat (Fecal) Digestibility	44.5^{C}	77.4^{B}	87.7^{A}	90.8^{A}	3.96

Figure 1. Eight-day nutrient retention trial data summary. Variables with significant *F* tests ($P \leq 0.05$) using one-way ANOVA were compared using Duncan's multiple range test. Means within a row with the same letter are not significantly different.

		Diets Containing 50% of Test Ingredient (n=6) CDC Teal	Dehulled CDC	Hulled CDC	Hulled Keet	STD Error
Val	Body Wt (g),	43.3	44.0	43.6	43.5	0.27
	Body Wt (g),	2011.6^{A,B}	1920.2^{B}	2025.9^{A}	2076.5^{A}	19.50
	Total Gain	1968.3^{A,B}	1876.1^{B}	1982.3^{A}	2032.9^{A}	19.50
	Total Cons	3135.8^{A,B}	2955.5^{B}	3127.1^{A,B}	3232.9^{A}	42.19
	G:F (0-35 d)	0.628	0.635	0.625	0.609	0.0067

Figure 2. Five-week broiler chicken performance trial data summary. Variables with significant *F* tests ($P \leq 0.05$) using one-way ANOVA were compared using Duncan's multiple range test. Means within a row with the same letter are not significantly different.

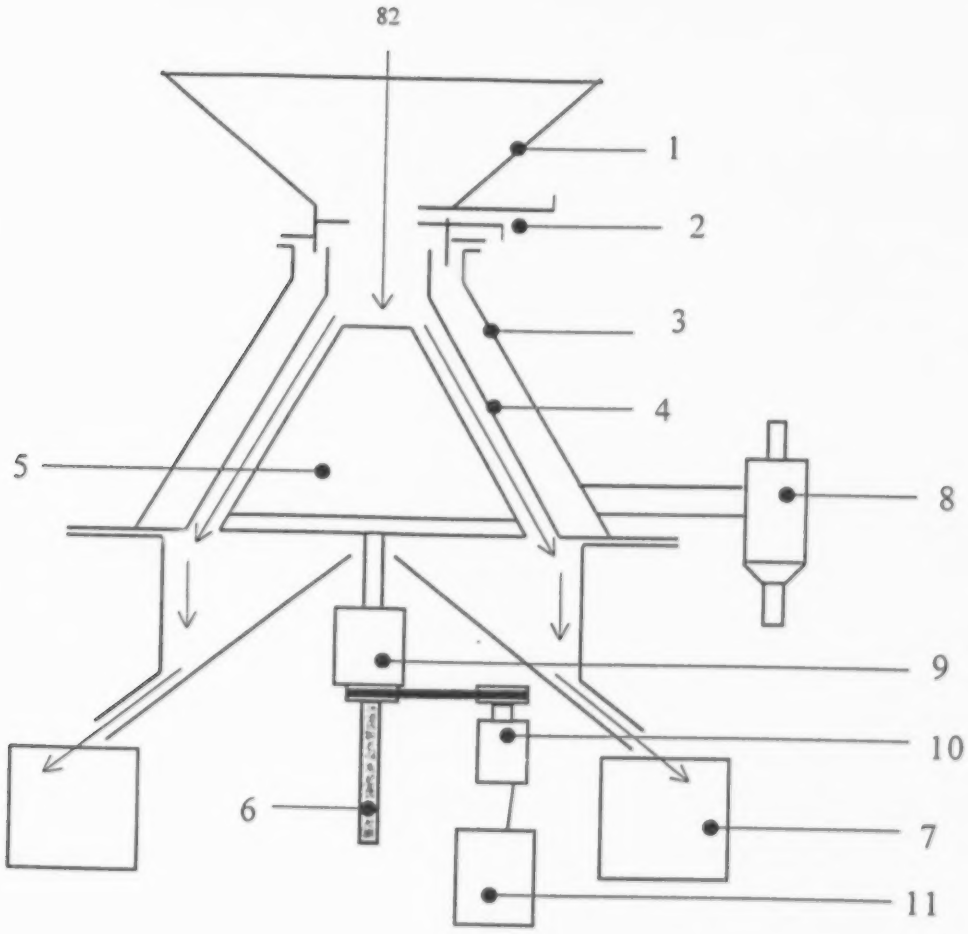

Fig. 3. Schematic flow/component diagram of a cone-type dehuller

1. Hopper
2. Guillotine-type seed flow regulator
3. Shroud section
4. Rubber lined screen section
5. Rubber-coated aluminum cone mounted on a splined shaft
6. Height adjustment rod
7. Bucket collection system
8. Cyclone for dust collection
9. Shaft receiver/bearing permitting vertical shaft movement
10. Motor and pulley drive system
11. Inverter speed control

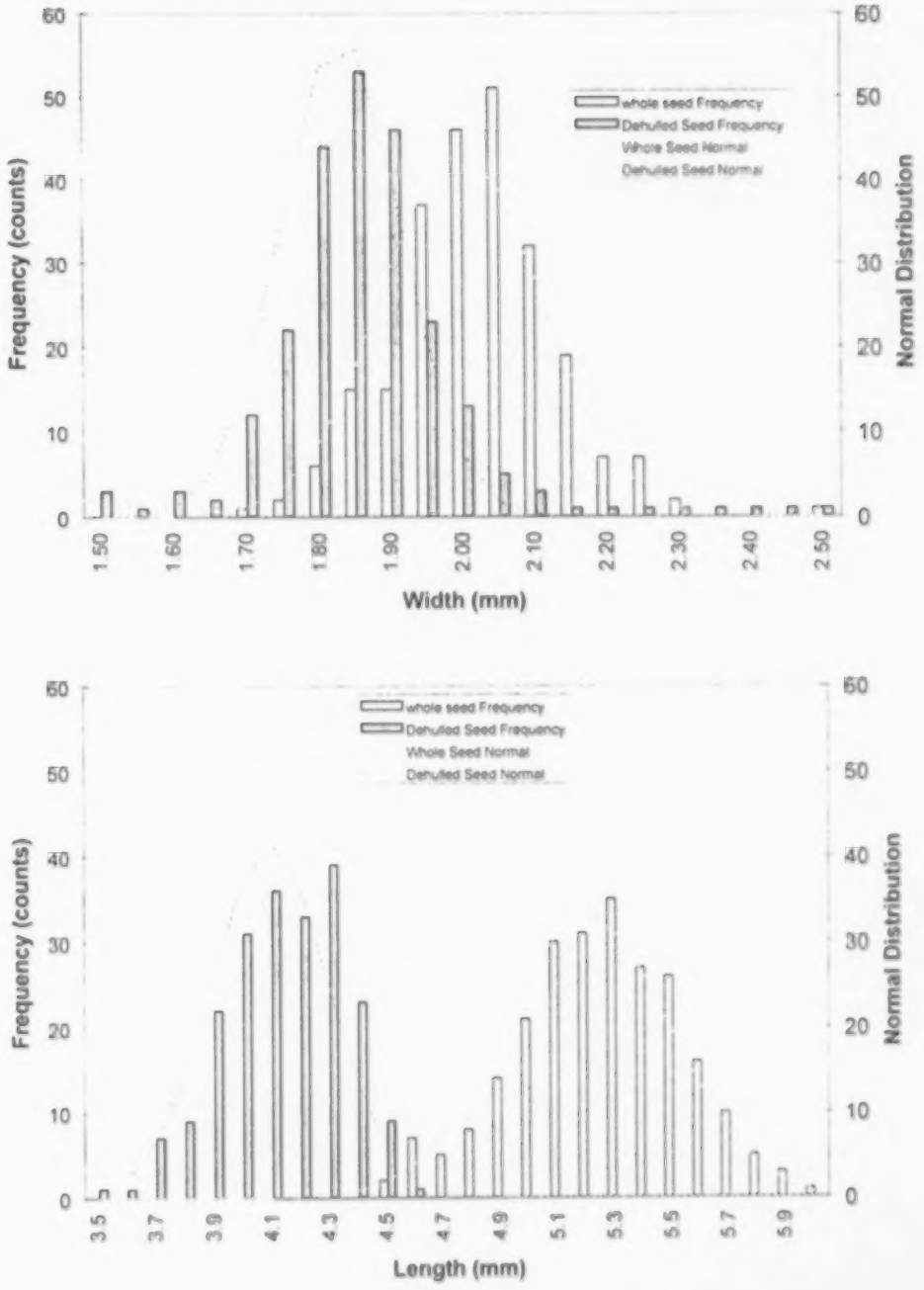

Fig. 4.Frequency distribution and normal probability plots of hairless canaryseed shape (width and length) measured by imaging 200 of hulled seeds and 200 of manually dehulled seeds

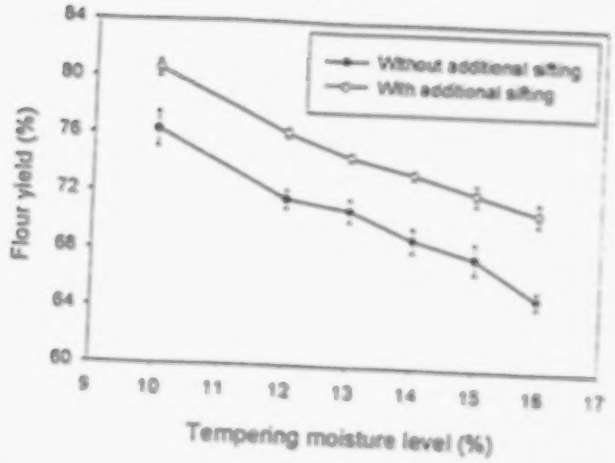

Fig. 5. Effect of tempering moisture level on flour yield of hairless canaryseed groats

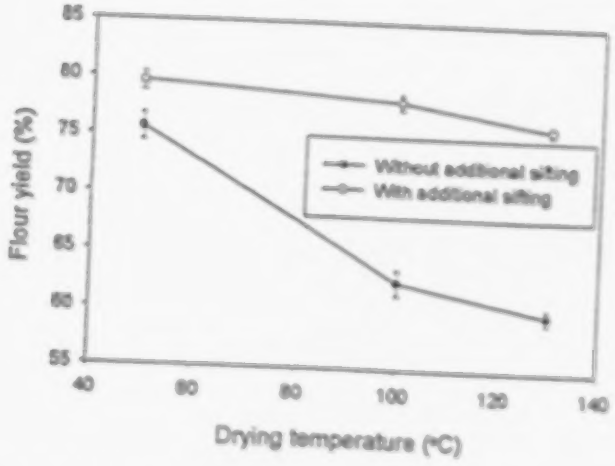

Fig. 6. Effect of soaking and drying on flour yield of hairless canaryseed groats

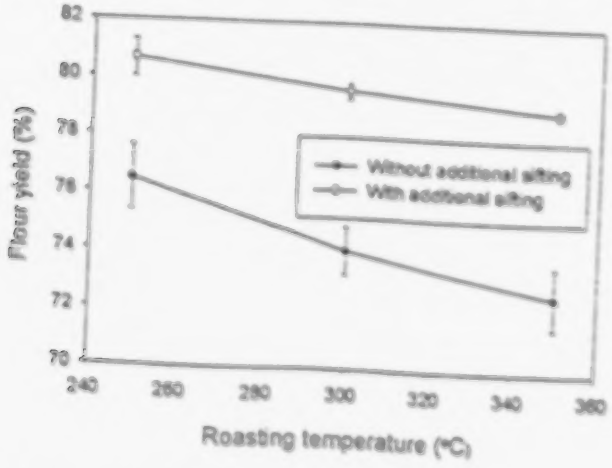

Fig. 7. Effect of roasting on flour yield of hairless canaryseed groats

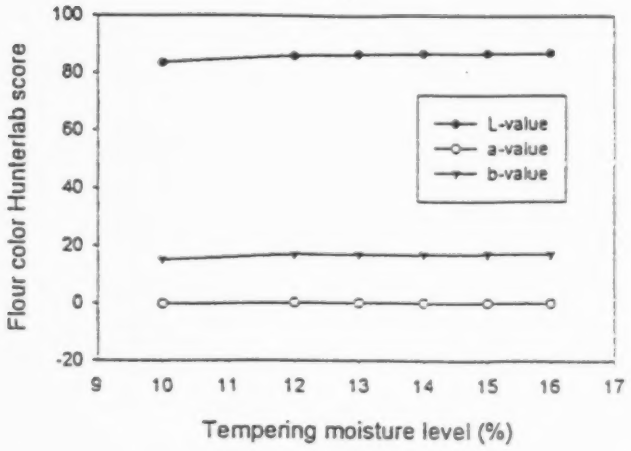

Fig. 8. Effect of tempering moisture level on flour color of hairless canaryseed groats

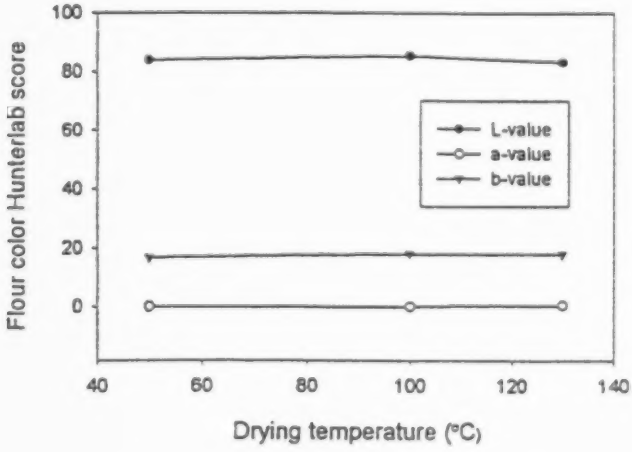

Fig. 9. Effect of soaking and drying on flour color of hairless canaryseed groats

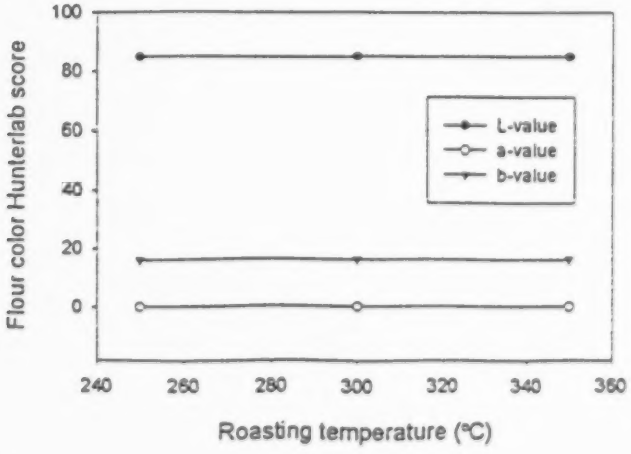

Fig. 10. Effect of roasting temperature on flour color of hairless canaryseed groats

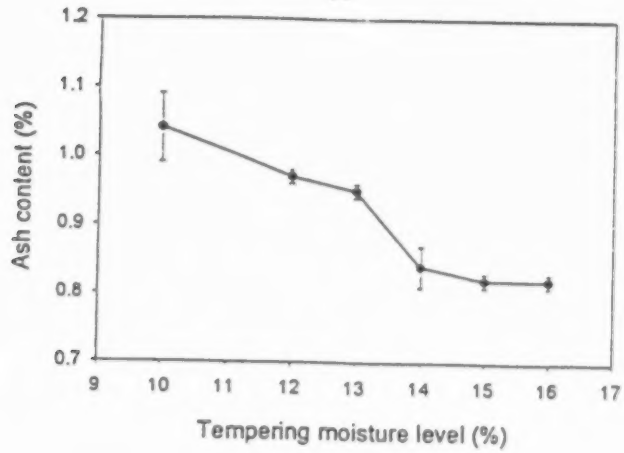

Fig. 11. Effect of tempering moisture level on ash content of hairless canaryseed flour

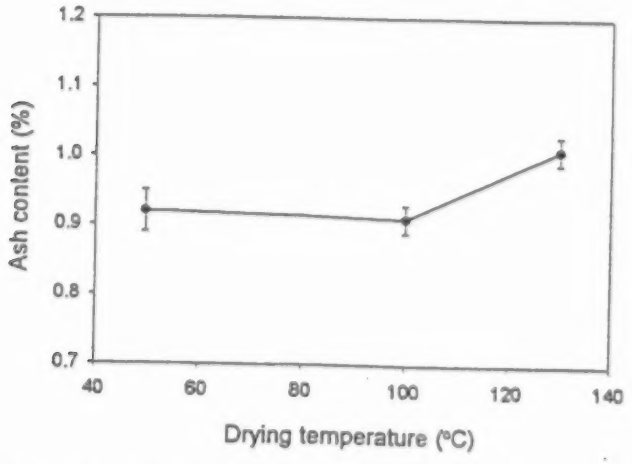

Fig. 12. Effect of soaking and drying on ash content of hairless canaryseed flour

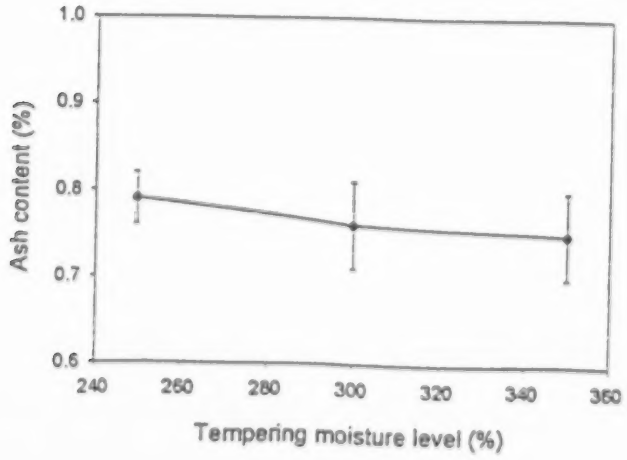

Fig. 13. Effect of roasting temperature on ash content of hairless canaryseed flour

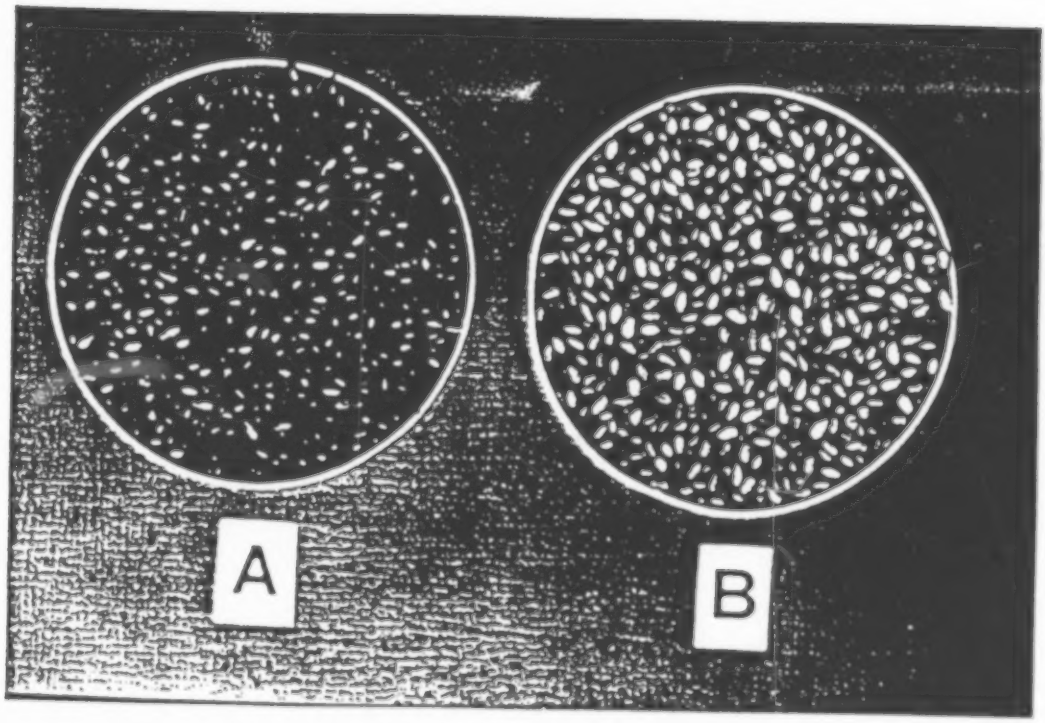

Fig. 14. Appearance of raw (A) and bleached (B) canaryseed groats.

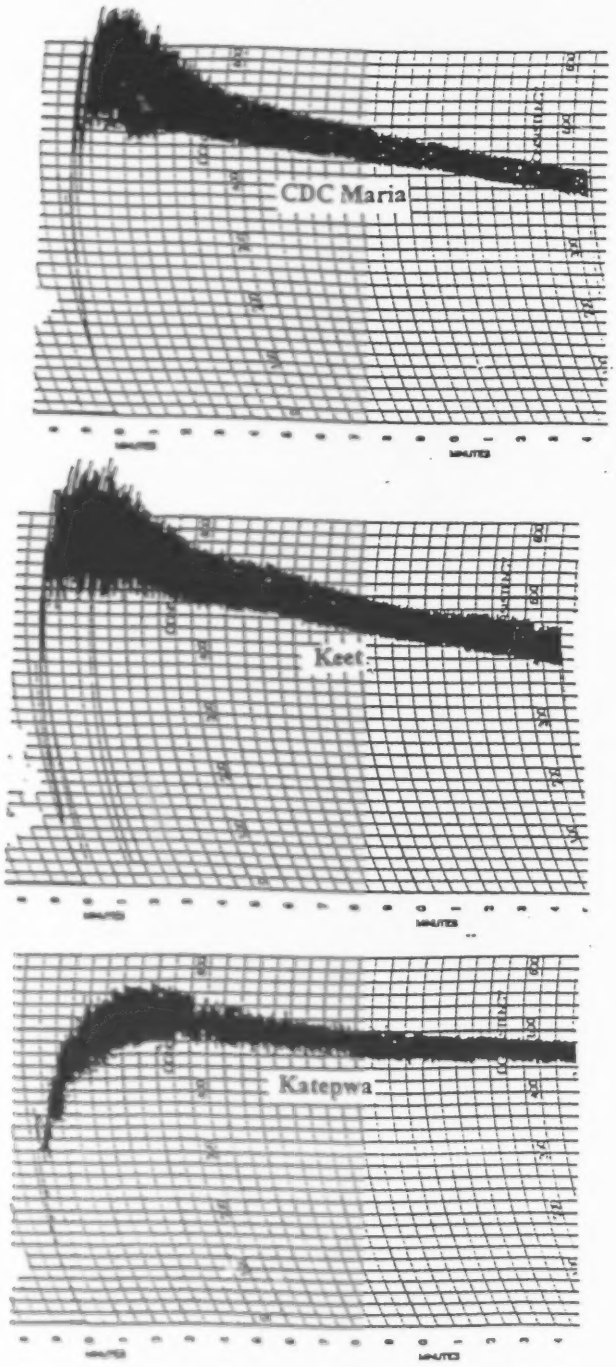

Fig. 15. Farinograph curves of canaryseed cultivars CDC Maria and Keet and CWRS wheat ciltivar Katepwa

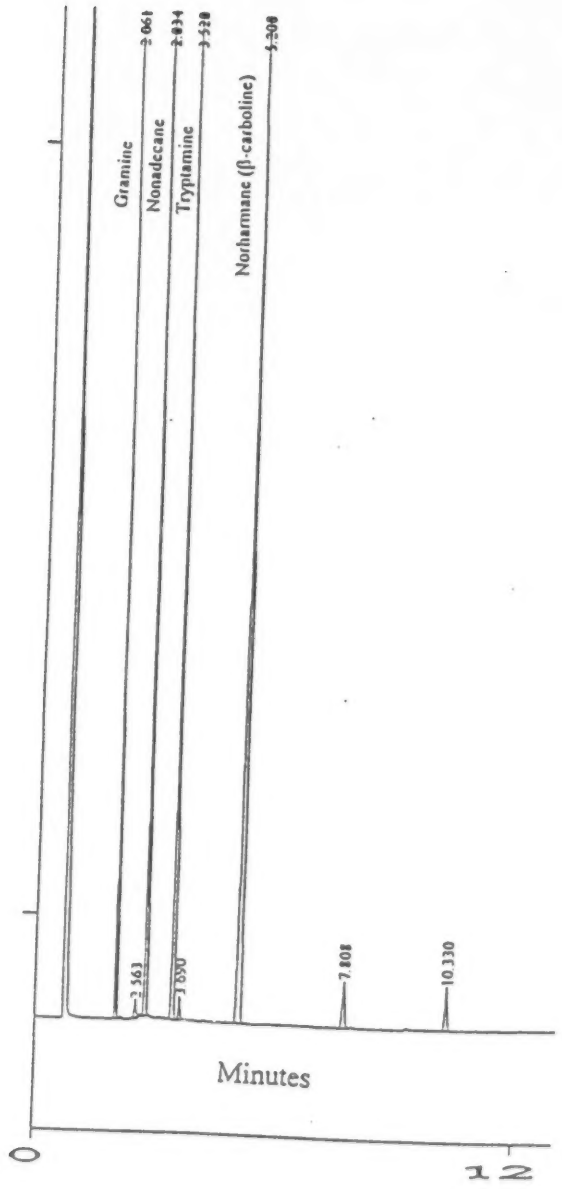

Fig. 16. GLC calibration standard chromatogram of trimethylsilyl derivatives of alkaloids

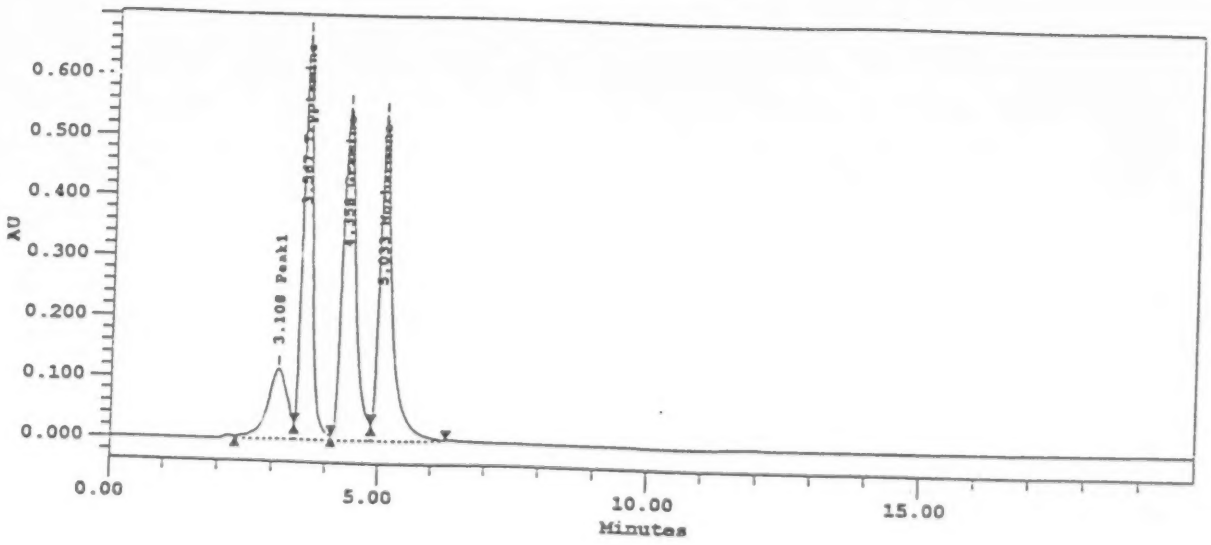

Fig. 17. HPLC calibration standard chromatogram of alkaloids

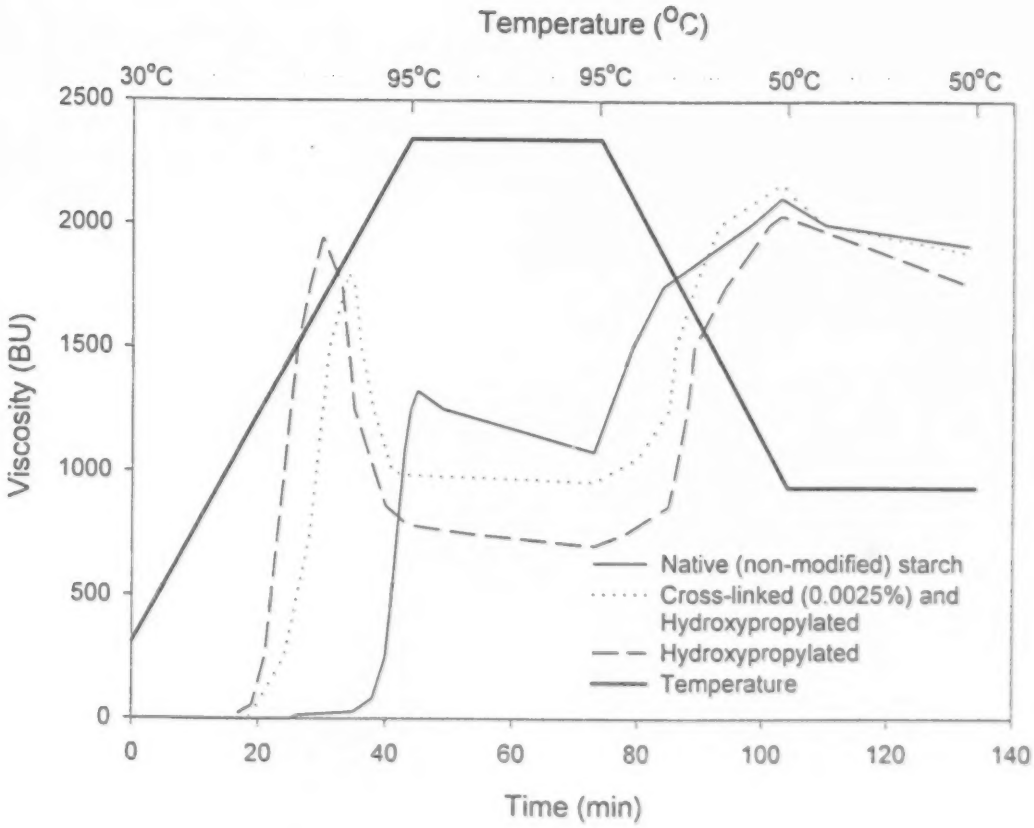

Fig. 18. Amylograph of native and modified canaryseed starch.

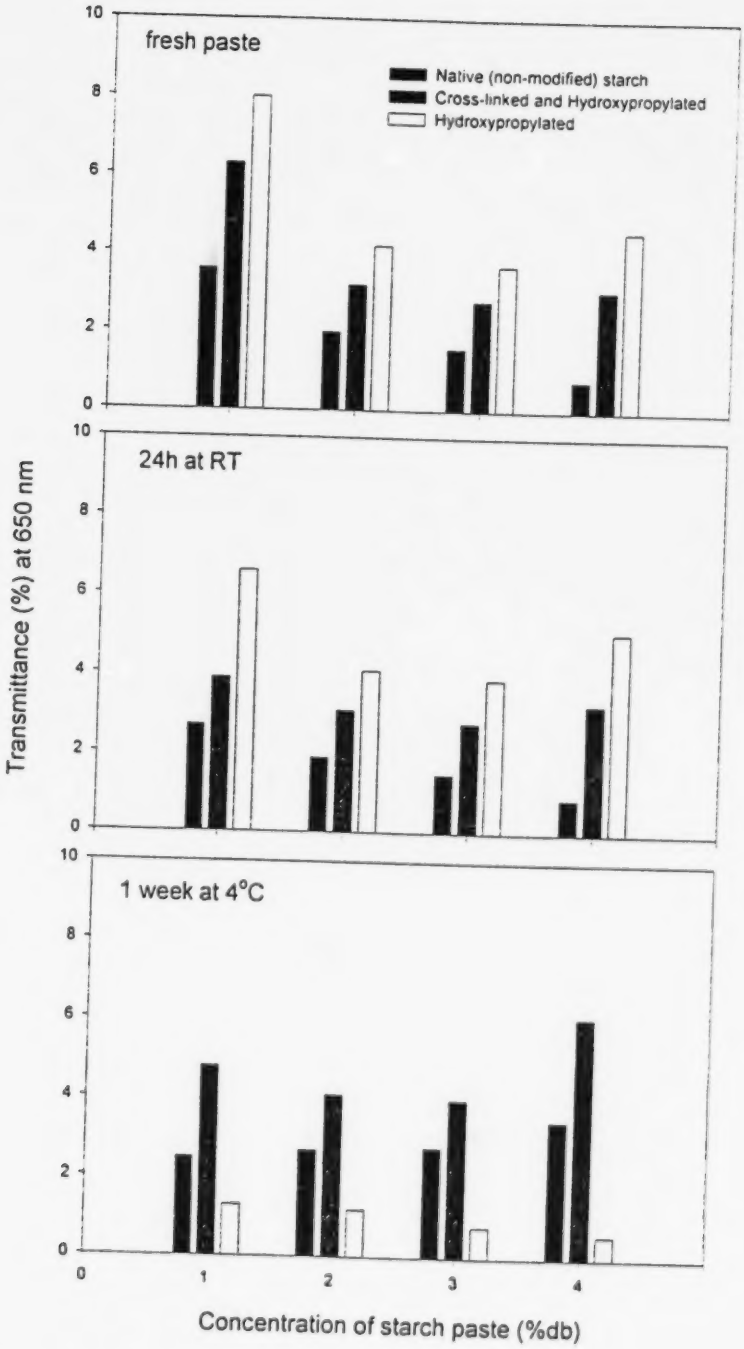

Fig. 19. Paste clarity of freshly cooked or refrigerated native and modified canary seed starches

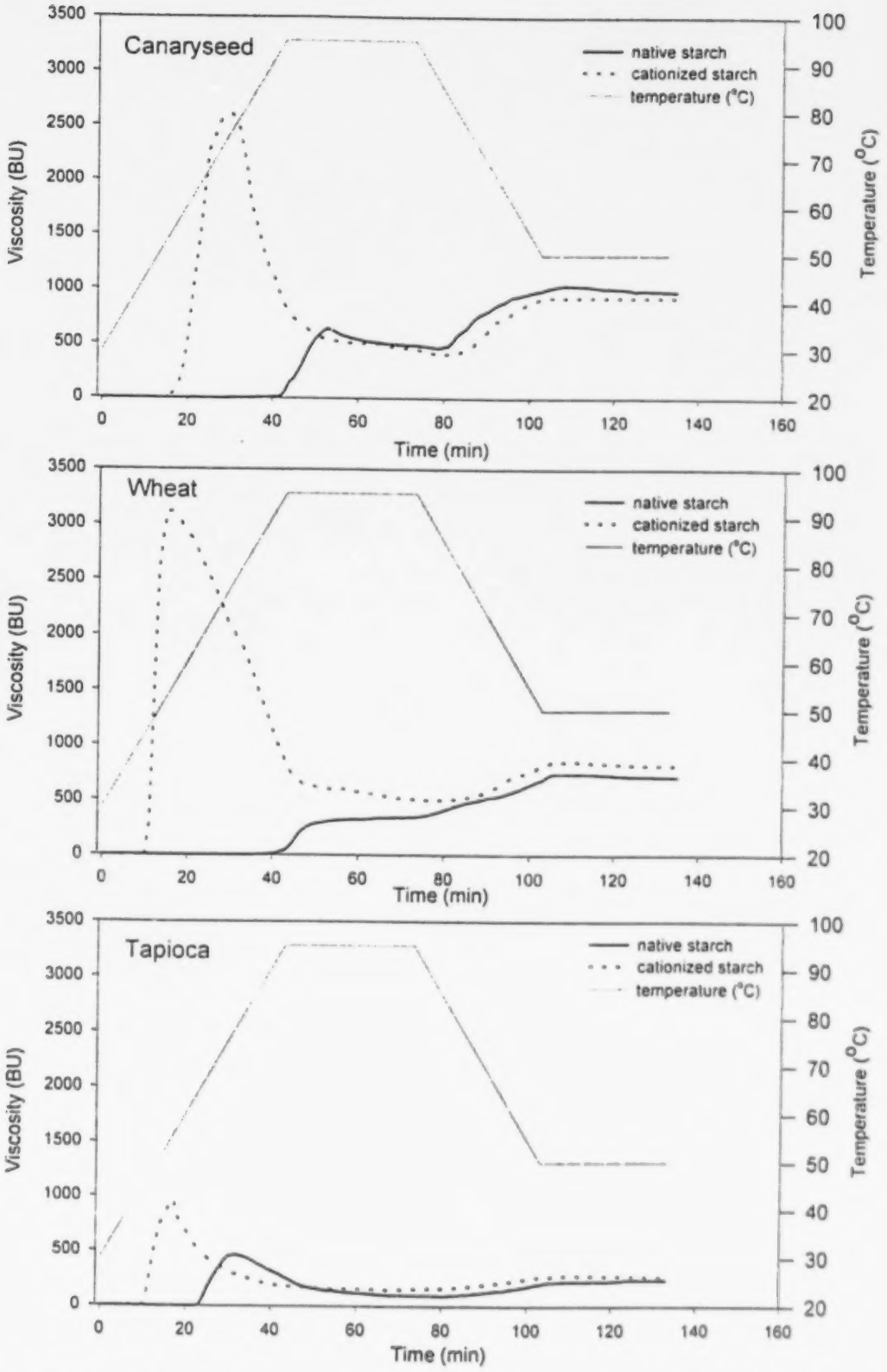

Fig. 20. Amylograph profile of native and cationized starches from canaryseed, wheat and taipoca

Appendix 1. Certificate for vomitoxin analysis in canaryseed and wheat

Industry Services Division
846 - 303 Main Street
Winnipeg, Manitoba
R3C 3G8

March 16, 1999.

Mr. Pierre Hucl
Crop Development Centre
University of Saskatchewan
51 Campus Drive
Saskatoon, SK
S7N 5A8

Dear Pierre:

We tested your samples (10 wheat and 20 canaryseed) for Vomitoxin, and they were found to be free of Vomitoxin within the limitations of the methology. The Elisa method is quantifiable above 0.5 ppm. Only one sample Kernen, Plot 802, TRT 2 showed DON=0.2 ppm. The sample was retested and similar results were again obtained.

We passed on the samples to Tom Nowicki's lab for Aflatoxin testing.

Yours sincerely,

John Antoniszyn

Appendix 2. Certificate for aflatoxin analysis in canaryseed and wheat

GRAIN RESEARCH LABORATORY
1404–303 Main Street
Winnipeg, Manitoba
R3C 3G8 Canada
Phone (204) 983-3036
Fax (204) 983-0724

April 1, 1999

CERTIFICATE OF ANALYSIS

The samples submitted by Pierre Huel, University of Saskatchewan, were analyzed by the Grain Research Laboratory for the presence of aflatoxins. The results of the analyses are listed in the following table:

Commodity	Station	Plot	Treatment	Results (PPB) Aflatoxin
RVT CNSD	Assiniboia	801	1	<5
RVT CNSD	Assiniboia	802	2	<5
RVT CNSD	Shellbrook	801	1	<5
RVT CNSD	Shellbrook	802	2	<5
RVT CNSD	Fox Valley	801	1	<5
RVT CNSD	Fox Valley	802	2	<5
RVT CNSD	Kernen	801	1	<5
RVT CNSD	Kernen	802	2	<5
RVT CNSD	Canora	801	1	<5
RVT CNSD	Canora	802	2	<5
RVT CNSD	Jedburgh	801	1	<5
RVT CNSD	Jedburgh	802	2	<5
RVT CNSD	Kelington	801	1	<5
RVT CNSD	Kelington	802	2	<5
RVT CNSD	Carlyle	801	1	<5
RVT CNSD	Carlyle	802	2	<5
RVT CNSD	Weyburn	801	1	<5
RVT CNSD	Weyburn	802	2	<5
RVT CNSD	Girvin	801	1	<5
RVT CNSD	Girvin	802	2	<5
RTV HRSW	Kelington	Ketepwa	1	<5
RTV HRSW	Nipawin	Ketepwa	1	<5
RTV HRSW	Jedburgh	Ketepwa	1	<5
RTV HRSW	Assiniboia	Ketepwa	1	<5

Commodity	Station	Plot	Treatment	Results (PPB) Aflatoxin
RTV HRSW	Weyburn	Ketepwa	1	<5
RTV HRSW	Shellbrook	Ketepwa	1	<5
RTV HRSW	Fox Valley	Ketepwa	1	<5
RTV HRSW	Kernen	Ketepwa	1	<5
RTV HRSW	Canora	Ketepwa	1	<5
RTV HRSW	Girvin	Ketepwa	1	<5

The symbol "<" means less than, i.e., not detected at a level equal to or above the lower limit of quantification of the analytical method.

N. Barchuk
Chemist In Charge, Certification Unit